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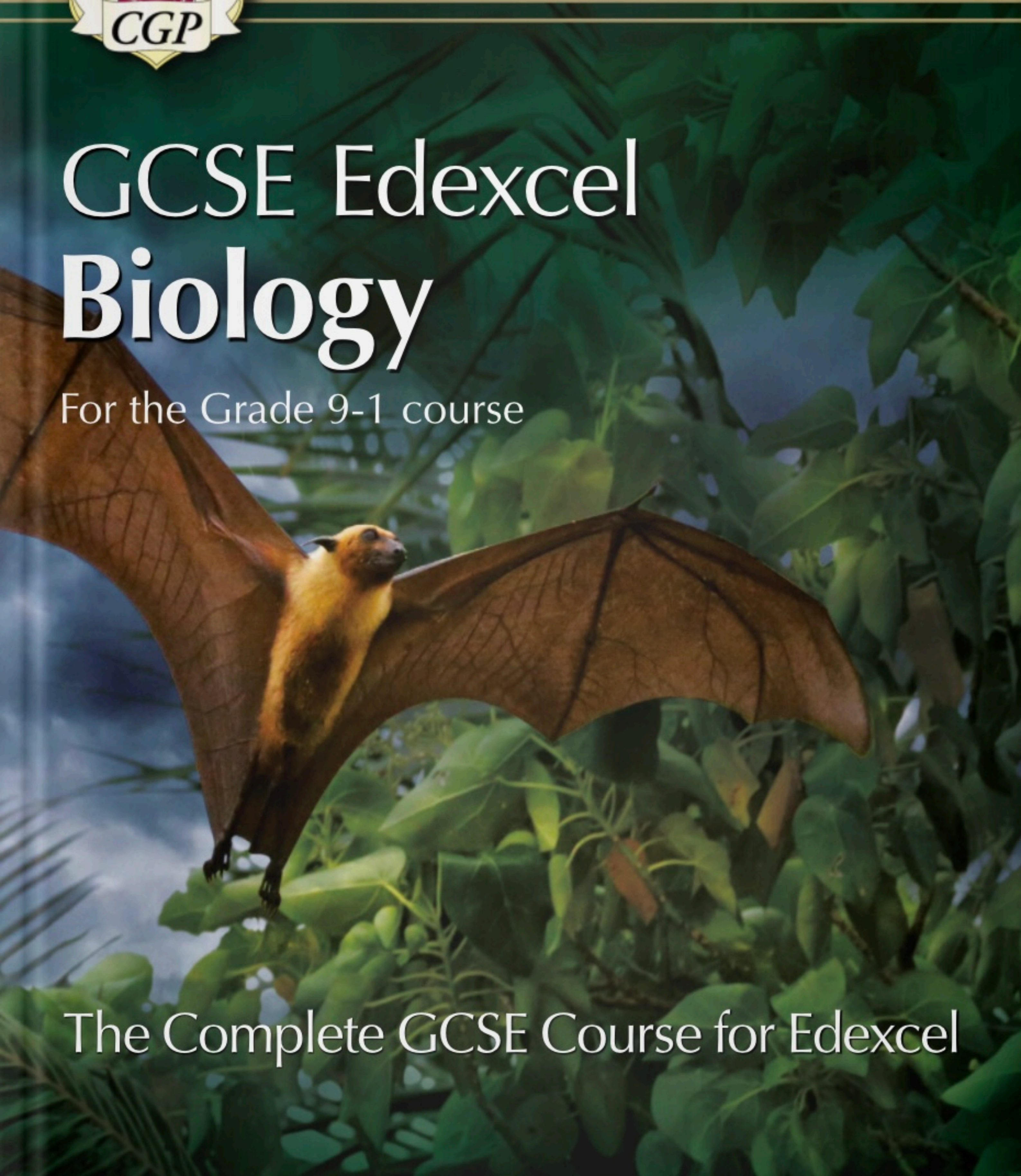

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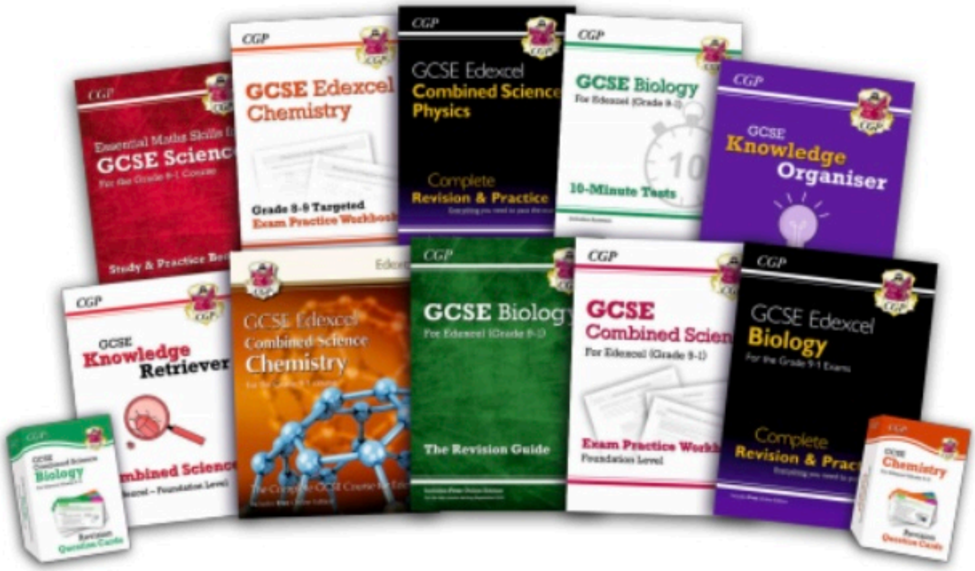
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How to use this book

Learning Objectives

- These tell you exactly what you need to learn, or be able to do, for the exam.
- There's a specification reference at the bottom that links to the Edexcel specification.

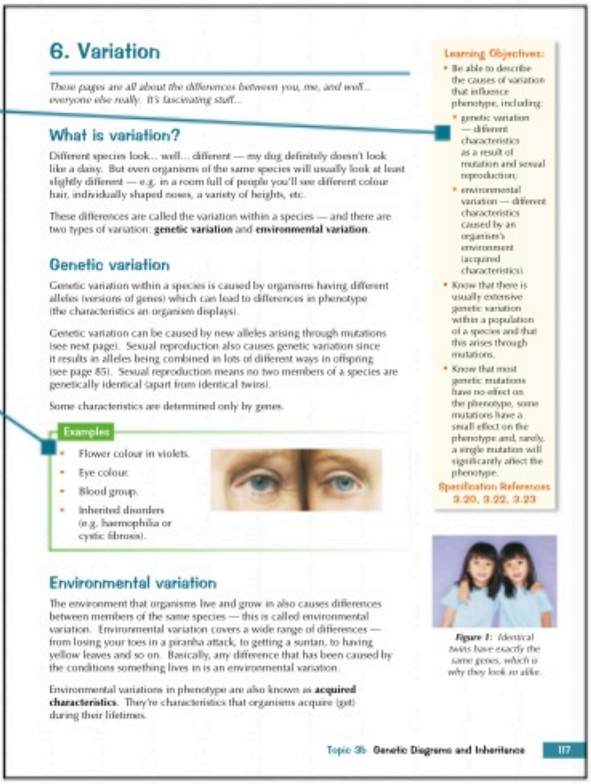
Examples

These are here to help you understand the theory.

Working Scientifically

- Working Scientifically is a big part of GCSE Biology. There's a whole section on it at the front of the book.
- Working Scientifically is also covered throughout this book wherever you see this symbol.

WORKING SCIENTIFICALLY



6. Variation

These pages are all about the differences between you, me, and well... everyone else really. It's fascinating stuff...

Learning Objectives:
- Be able to describe the causes of variation that influence phenotype, including:
  - genetic variation — different characteristics as a result of mutation and sexual reproduction;
  - environmental variation — different characteristics caused by an organism's environment (acquired characteristics).
- Know that there is usually extensive genetic variation within a population of a species and that this arises through mutations.
- Know that most genetic mutations have no effect on the phenotype, some mutations have a small effect on the phenotype and, rarely, a single mutation will significantly affect the phenotype.

Specification References
3.20, 3.22, 3.23

What is variation?

Different species look... well... different — my dog definitely doesn't look like a daisy. But even organisms of the same species will usually look at least slightly different — e.g. in a room full of people you'll see different colour hair, individually shaped noses, a variety of heights, etc.

These differences are called the variation within a species — and there are two types of variation: **genetic variation** and **environmental variation**.

Genetic variation

Genetic variation within a species is caused by organisms having different alleles (versions of genes) which can lead to differences in phenotype (the characteristics an organism displays).

Genetic variation can be caused by new alleles arising through mutations (see next page). Sexual reproduction also causes genetic variation since it results in alleles being combined in lots of different ways in offspring (see page 85). Sexual reproduction means no two members of a species are genetically identical (apart from identical twins).

Some characteristics are determined only by genes.

Examples
- Flower colour in violets.
- Eye colour.
- Blood group.
- Inherited disorders (e.g. haemophilia or cystic fibrosis).

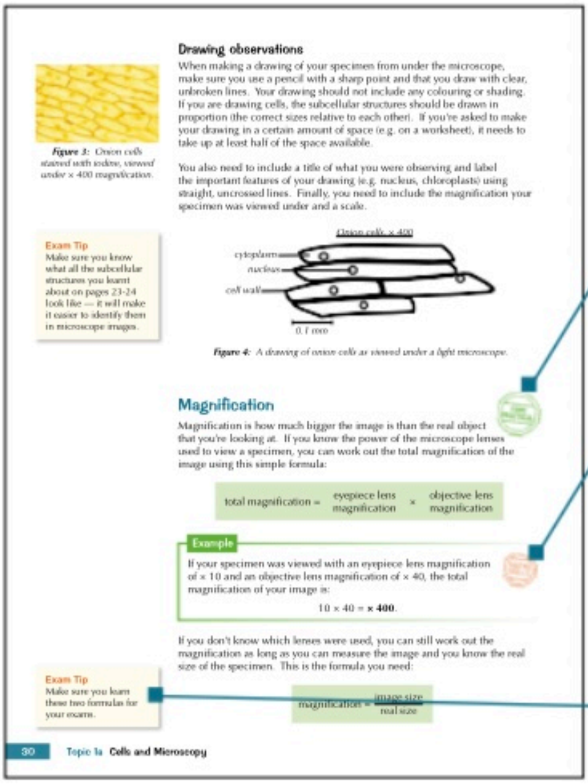
Figure 1: Identical twins have exactly the same genes, which is why they look so alike.

Environmental variation

The environment that organisms live and grow in also causes differences between members of the same species — this is called environmental variation. Environmental variation covers a wide range of differences — from losing your toes in a piranha attack, to getting a suntan, to having yellow leaves and so on. Basically, any difference that has been caused by the conditions something lives in is an environmental variation.

Environmental variations in phenotype are also known as **acquired characteristics**. They're characteristics that organisms acquire (get) during their lifetimes.

Topic 3b **Genetic Diagrams and Inheritance** 117



Drawing observations

When making a drawing of your specimen from under the microscope, make sure you use a pencil with a sharp point and that you draw with clear, unbroken lines. Your drawing should not include any colouring or shading. If you are drawing cells, the subcellular structures should be drawn in proportion (the correct sizes relative to each other). If you're asked to make your drawing in a certain amount of space (e.g. on a worksheet), it needs to take up at least half of the space available.

Figure 3: Onion cells stained with iodine, viewed under × 400 magnification.

You also need to include a title of what you were observing and label the important features of your drawing (e.g. nucleus, chloroplasts) using straight, uncrossed lines. Finally, you need to include the magnification your specimen was viewed under and a scale.

Exam Tip
Make sure you know what all the subcellular structures you learnt about on pages 23-24 look like — it will make it easier to identify them in microscope images.

Figure 4: A drawing of onion cells as viewed under a light microscope.

Magnification

Magnification is how much bigger the image is than the real object that you're looking at. If you know the power of the microscope lenses used to view a specimen, you can work out the total magnification of the image using this simple formula:

$$\text{total magnification} = \text{eyepiece lens magnification} \times \text{objective lens magnification}$$

Example

If your specimen was viewed with an eyepiece lens magnification of × 10 and an objective lens magnification of × 40, the total magnification of your image is:

10 × 40 = **× 400**.

If you don't know which lenses were used, you can still work out the magnification as long as you can measure the image and you know the real size of the specimen. This is the formula you need:

$$\text{magnification} = \frac{\text{image size}}{\text{real size}}$$

Exam Tip
Make sure you learn these two formulas for your exams.

30 Topic 1a **Cells and Microscopy**

Core Practicals

There are some Core Practicals that you'll be expected to do throughout your course. You need to know all about them for the exams. They're all marked with stamps like this.

CORE PRACTICAL

Maths Skills

- There's a range of maths skills you could be expected to apply in your exams. The section on pages 324-331 is packed with plenty of maths that you'll need to be familiar with.
- Examples that show these maths skills in action are marked up with this symbol.

MATHS SKILLS

Tips and Exam Tips

- There are tips throughout this book to help you understand the theory.
- There are also exam tips to help you with answering exam questions.

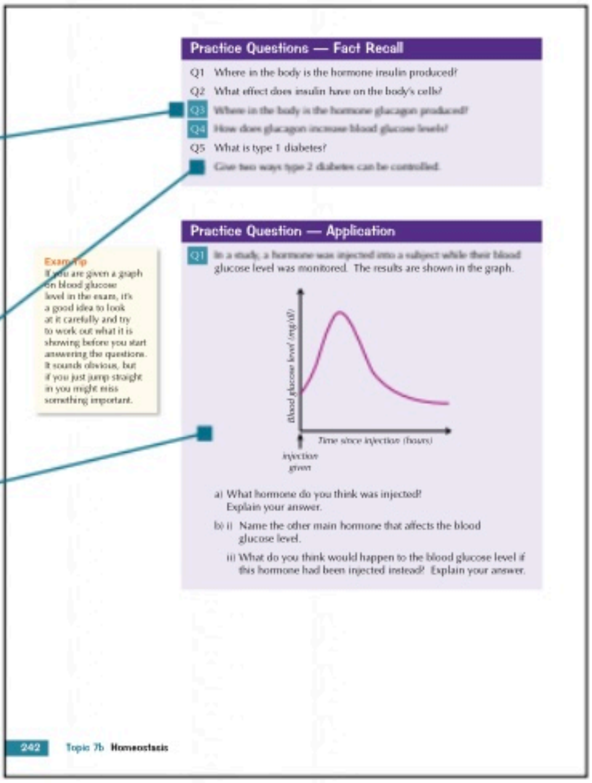
Higher Exam Material

- Some of the material in this book will only come up in the exam if you're sitting the higher exam papers.
- This material is clearly marked with boxes that look like this:

Higher **H** **Q1**

Practice Questions

- Fact recall questions test that you know the facts needed for GCSE Biology.
- Annoyingly, the examiners also expect you to be able to apply your knowledge to new situations — application questions give you plenty of practice at doing this.
- All the answers are in the back of the book.



Practice Questions — Fact Recall

Q1 Where in the body is the hormone insulin produced?

Q2 What effect does insulin have on the body's cells?

Q3 Where in the body is the hormone glucagon produced?

Q4 How does glucagon increase blood glucose levels?

Q5 What is type 1 diabetes?

Give two ways type 2 diabetes can be controlled.

Exam Tip

If you are given a graph on blood glucose level in the exam, it's a good idea to look at it carefully and try to work out what it is showing before you start answering the questions. It sounds obvious, but if you just jump straight in you might miss something important.

Practice Question — Application

Q1 In a study, a hormone was injected into a subject while their blood glucose level was monitored. The results are shown in the graph.

a) What hormone do you think was injected? Explain your answer.

b) i) Name the other main hormone that affects the blood glucose level.

ii) What do you think would happen to the blood glucose level if this hormone had been injected instead? Explain your answer.

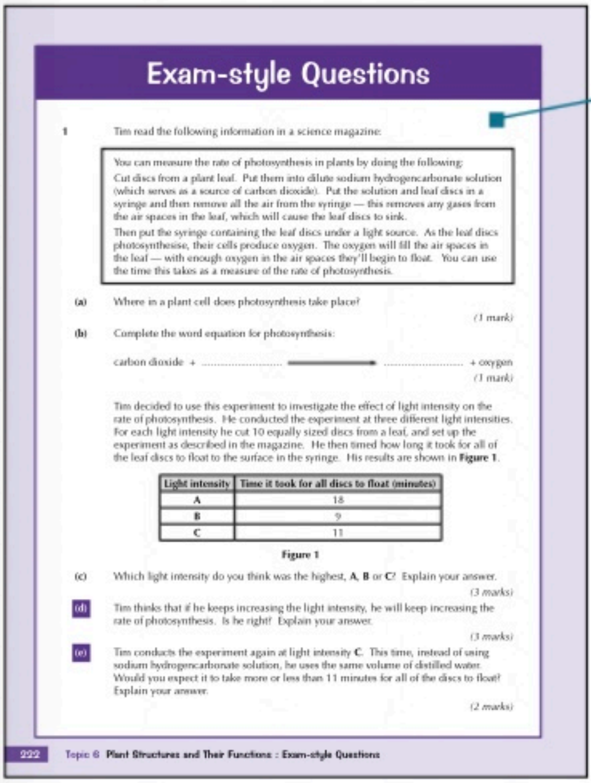
242 Topic 7b Homeostasis

Practical Skills

There's also a whole section on pages 316-323 with extra details on practical skills you'll be expected to use in the Core Practicals, and apply knowledge of in the exams.

Topic Checklist

Each topic has a checklist at the end with boxes that let you tick off what you've learnt.



Exam-style Questions

1 Tim read the following information in a science magazine:

> You can measure the rate of photosynthesis in plants by doing the following:
>
> Cut discs from a plant leaf. Put them into dilute sodium hydrogencarbonate solution (which serves as a source of carbon dioxide). Put the solution and leaf discs in a syringe and then remove all the air from the syringe — this removes any gases from the air spaces in the leaf, which will cause the leaf discs to sink.
>
> Then put the syringe containing the leaf discs under a light source. As the leaf discs photosynthesise, their cells produce oxygen. The oxygen will fill the air spaces in the leaf — with enough oxygen in the air spaces they'll begin to float. You can use the time this takes as a measure of the rate of photosynthesis.

(a) Where in a plant cell does photosynthesis take place?

(1 mark)

(b) Complete the word equation for photosynthesis:

carbon dioxide + ………………… ⟶ ………………… + oxygen

(1 mark)

Tim decided to use this experiment to investigate the effect of light intensity on the rate of photosynthesis. He conducted the experiment at three different light intensities. For each light intensity he cut 10 equally sized discs from a leaf, and set up the experiment as described in the magazine. He then timed how long it took for all of the leaf discs to float to the surface in the syringe. His results are shown in **Figure 1**.

Light intensity	Time it took for all discs to float (minutes)
A	18
B	9
C	11

Figure 1

(c) Which light intensity do you think was the highest, **A**, **B** or **C**? Explain your answer.

(3 marks)

(d) Tim thinks that if he keeps increasing the light intensity, he will keep increasing the rate of photosynthesis. Is he right? Explain your answer.

(3 marks)

(e) Tim conducts the experiment again at light intensity **C**. This time, instead of using sodium hydrogencarbonate solution, he uses the same volume of distilled water. Would you expect it to take more or less than 11 minutes for all of the discs to float? Explain your answer.

(2 marks)

222 Topic 6 Plant Structures and Their Functions : Exam-style Questions

Exam-style Questions

- Practising exam-style questions is really important — this book has some at the end of every topic to test you.
- They're the same style as the ones you'll get in the real exams.
- All the answers are in the back of the book, along with a mark scheme to show you how you get the marks.
- Higher-only questions are marked like this: **1** **(a)** **(i)**

Glossary

There's a glossary at the back of the book full of definitions you need to know for the exam, plus loads of other useful words.

Exam Help

There's a section at the back of the book stuffed full of things to help you with the exams.

Working Scientifically

1. The Scientific Method

Science is all about finding things out and learning things about the world we live in. This section is all about the scientific process — how a scientist's initial idea turns into a theory that is accepted by the wider scientific community.

Hypotheses

Scientists try to explain things. Everything. They start by observing something they don't understand — it could be anything, e.g. planets in the sky, a person suffering from an illness, what matter is made of... anything.

Then, they come up with a **hypothesis** — a possible explanation for what they've observed. (Scientists can also sometimes form a model — a description or a representation of what's physically going on — see page 3).

The next step is to test whether the hypothesis might be right or not. This involves making a **prediction** based on the hypothesis and testing it by gathering evidence (i.e. data) from investigations. If evidence from experiments backs up a prediction, you're a step closer to figuring out if the hypothesis is true.

Tip: Investigations include lab experiments and studies.

Testing a hypothesis

Normally, scientists share their findings in peer-reviewed journals, or at conferences. **Peer-review** is where other scientists check results and scientific explanations to make sure they're 'scientific' (e.g. that experiments have been done in a sensible way) before they're published. It helps to detect false claims, but it doesn't mean that findings are correct — just that they're not wrong in any obvious way.

Once other scientists have found out about a hypothesis, they'll start basing their own predictions on it and carry out their own experiments. They'll also try to reproduce the original experiments to check the results — and if all the experiments in the world back up the hypothesis, then scientists start to think the hypothesis is true.

However, if a scientist somewhere in the world does an experiment that doesn't fit with the hypothesis (and other scientists can reproduce these results), then the hypothesis is in trouble. When this happens, scientists have to come up with a new hypothesis (maybe a modification of the old hypothesis, or maybe a completely new one).

Tip: Sometimes it can take a really long time for a hypothesis to be accepted.

Accepting a hypothesis

If pretty much every scientist in the world believes a hypothesis to be true because experiments back it up, then it usually goes in the textbooks for students to learn. Accepted hypotheses are often referred to as **theories**.

Our currently accepted theories are the ones that have survived this 'trial by evidence' — they've been tested many, many times over the years and survived (while the less good ones have been ditched). However... they never, never become hard and fast, totally indisputable fact. You can never know... it'd only take one odd, totally inexplicable result, and the hypothesising and testing would start all over again.

Example

Over time scientists have come up with different hypotheses about how illnesses are caused:

- Hundreds of years ago, we thought demons caused illness.
- Then we thought it was caused by 'bad blood' (and treated it with leeches).
- Now we've collected more evidence, we know that illnesses that can be spread between people are due to microorganisms.

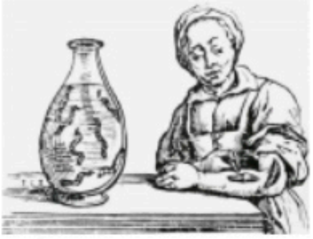


Figure 1: *Historical artwork of a woman using leeches to treat disease.*

Models

Models are used to describe or display how an object or system behaves in reality. They're often based on evidence collected from experiments, and should be able to accurately predict what will happen in other, similar experiments. There are different types of models that scientists can use to describe the world around them. Here are just a few:

- A **descriptive model** describes what's happening in a certain situation, without explaining why. It won't necessarily include details that could be used to predict the outcome of a different scenario. For example, a graph showing the measured rate of an enzyme-catalysed reaction at different temperatures would be a descriptive model.
- A **representational model** is a simplified description or picture of what's going on in real life. It can be used to explain observations and make predictions. E.g. the lock and key model of enzyme action is a simplified way of showing how enzymes work(see pages 36-37). It can be used to explain why enzymes only catalyse particular reactions.
- **Spatial models** are used to analyse the way that data is arranged within a physical space. For example, a spatial model could be used to look for relationships between the distribution of a species and physical aspects of its environment.
- **Computational models** use computers to make simulations of complex real-life processes, such as climate change. They're used when there are a lot of different variables (factors that change) to consider, and because you can easily change their design to take into account new data.
- **Mathematical models** can be used to describe the relationship between variables in numerical form (e.g. as an equation), and therefore predict outcomes of a scenario. For example, an equation can be written to predict how quickly molecules will diffuse into cells based on factors such as how large they are. On a larger scale, a mathematical model can be used to predict the way that a disease might spread through a population, e.g. by estimating the number of people that will become infected with the disease based on the number of people that are currently infected.

Tip: Like hypotheses, models have to be tested before they're accepted by other scientists. You can test models by using them to make a prediction, and then carrying out an investigation to see whether the evidence matches the prediction.

Tip: Mathematical models are made using patterns found in data and also using information about known relationships between variables.

Tip: Like hypotheses, models are constantly being revised and modified, based on new data.

All models have limitations on what they can explain or predict. Climate change models have several limitations — for example, it's hard to take into account all the biological and chemical processes that influence climate. It can also be difficult to include regional variations in climate.

Communicating results

Some scientific discoveries show that people should change their habits, or they might provide ideas that could be developed into new technology. So scientists need to tell the world about their discoveries.

Tip: New scientific discoveries are usually communicated to the public in the news or via the internet. They might be communicated to governments and large organisations via reports or meetings.

Example

Gene technologies make use of discoveries that scientists have made about genes and DNA. Some of these technologies are used in genetic engineering, to produce genetically modified crops. Information about these crops needs to be communicated to farmers who might benefit from growing them, and to the general public so they can make informed decisions about the food they buy and eat.

Reports about scientific discoveries in the media (e.g. newspapers or television) aren't peer-reviewed. This means that, even though news stories are often based on data that has been peer-reviewed, the data might be presented in a way that is over-simplified or inaccurate, leaving it open to misinterpretation.

Tip: If you're reading an article about a new scientific discovery, always think about how the study was carried out. It may be that the sample size was very small, and so the results aren't representative of the whole situation (see page 11 for more on sample sizes).

It's important that the evidence isn't presented in a **biased** way. This can sometimes happen when people want to make a point, e.g. they overemphasise a relationship in the data. (Sometimes without knowing they're doing it.) There are all sorts of reasons why people might want to do this.

Tip: An example of bias is a newspaper article describing details of data supporting an idea without giving any of the evidence against it.

Examples

- They want to keep the organisation or company that's funding the research happy. (If the results aren't what they'd like they might not give them any more money to fund further research.)
- Governments might want to persuade voters, other governments or journalists to agree with their policies about a certain issue.
- Companies might want to 'big up' their products, or make impressive safety claims.
- Environmental campaigners might want to persuade people to behave differently.

There's also a risk that if an investigation is done by a team of highly-regarded scientists it'll be taken more seriously than evidence from less well known scientists. But having experience, authority or a fancy qualification doesn't necessarily mean the evidence is good — the only way to tell is to look at the evidence scientifically (e.g. is it repeatable, valid, etc. — see page 9).

2. Scientific Applications and Issues

New scientific discoveries can lead to exciting new ways of using science in our everyday lives. Unfortunately, these developments may also come with social, economic, environmental or personal problems that need to be considered.

Using scientific developments

Lots of scientific developments go on to have useful applications.

Examples

- When it was discovered that penicillin acted as an antibiotic, drugs were developed that used penicillin to treat bacterial infections.
- As scientists have investigated the role of reproductive hormones in the body, treatments that use these hormones have been developed to allow women to become pregnant who wouldn't be able to otherwise.

Tip: There's lots more about antibiotics on page 178.

Issues created by science

Scientific developments (e.g. new technologies or new advice) can create issues. For example, they could create political issues, which could lead to developments being ignored, or governments being slow to act if they think responding to the developments could affect their popularity with voters.

Example

Some governments were pretty slow to accept the fact that human activities are causing global warming, despite all the evidence. This is because accepting it means they've got to do something about it, which costs money and could hurt their economy. This could lose them a lot of votes.

Tip: See page 296 for more on global warming.

Scientific developments can cause a whole host of other issues too.

Examples

- Economic issues: Society can't always afford to do things scientists recommend (e.g. investing heavily in alternative energy sources) without cutting back elsewhere.
- Social issues: Decisions based on scientific evidence affect people — e.g. should junk food be taxed more highly (to encourage people to be healthy)? Should alcohol be banned (to prevent health problems)? Would the effect on people's lifestyles be acceptable?
- Environmental issues: Human activity often affects the natural environment — e.g. genetically modified crops may help us produce more food, but some people think they could cause environmental problems.
- Personal issues: Some decisions will affect individuals. For example, someone might support alternative energy, but object if a wind farm is built next to their house.

Figure 1: *Solar farms can be used to generate 'clean' electricity, but some people think that the money needed to invest in them should be spent elsewhere.*

3. Limitations of Science

Science has taught us an awful lot about the world we live in and how things work — but science doesn't have the answer for everything.

Questions science hasn't answered yet

We don't understand everything. And we never will. We'll find out more, for sure — as more hypotheses are suggested, and more experiments are done. But there'll always be stuff we don't know.

Examples

- Today we don't know as much as we'd like about the impacts of global warming. How much will sea levels rise? And to what extent will weather patterns change?
- We also don't know anywhere near as much as we'd like about the universe. Are there other life forms out there? And what is the universe made of?

Figure 1: *Global warming could cause weather patterns to change — which may result in longer, hotter droughts in some areas.*

In order to answer scientific questions, scientists need data to provide evidence for their hypotheses. Some questions can't be answered yet because the data can't currently be collected, or because there's not enough data to support a theory. But eventually, as we get more evidence, we probably will be able to answer these questions once and for all. By then there'll be loads of new questions to answer though.

Questions science can't answer

There are some questions that all the experiments in the world won't help us answer — for example, the "should we be doing this at all?" type questions.

Tip: Some experiments have to be approved by ethics committees before scientists are allowed to carry them out. This stops scientists from getting wrapped up in whether they can do something, before anyone stops to think about whether they should do it.

Example

Think about new drugs which can be taken to boost your 'brain power'.

- Some people think they're good as they could improve concentration or memory. New drugs could let people think in ways beyond the powers of normal brains.
- Other people say they're bad — they could give you an unfair advantage in exams. And people might be pressured into taking them so that they could work more effectively, and for longer hours.

The question of whether something is morally or ethically right or wrong can't be answered by more experiments — there is no "right" or "wrong" answer. The best we can do is get a consensus from society — a judgement that most people are more or less happy to live by. Science can provide more information to help people make this judgement, and the judgement might change over time. But in the end it's up to people and their consciences.

4. Risks and Hazards

A lot of things we do could cause us harm. But some things are more hazardous than they at first seem, whereas other things are less hazardous. This may sound confusing, but it'll all become clear...

What are risks and hazards?

A **hazard** is something that could potentially cause harm. All hazards have a **risk** attached to them — this is the chance that the hazard will cause harm.

The risks of some things seem pretty obvious, or we've known about them for a while, like the risk of causing acid rain by polluting the atmosphere, or of having a car accident when you're travelling in a car.

New technology arising from scientific advances can bring new risks. These risks need to be thought about alongside the potential benefits of the technology, in order to make a decision about whether it should be made available to the general public.

Example

Radiotherapy is a cancer treatment that uses radiation to kill cancer cells. However, radiation itself carries a risk of causing cancer in the patient.

The risk of cancer caused by radiotherapy has to be weighed against the risk of the existing cancer that needs to be treated.

In most cases, the risk from the original cancer far outweighs the risk from radiotherapy, which is why it is available to be used as a treatment.

Tip: The application of a new technology can change over time if new risks are discovered. For example, radiation was widely used as a medical treatment before it was known that it can cause cancer. These days, its use as a treatment is a lot more limited and techniques have been improved to reduce the risk.

Estimating risk

You can estimate the risk based on how many times something happens in a big sample (e.g. 100 000 people) over a given period (e.g. a year). For example, you could assess the risk of a driver crashing by recording how many people in a group of 100 000 drivers crashed their cars over a year.

To make a decision about an activity that involves a hazardous event, we don't just need to take into account the chance of the event causing harm, but also how serious the consequences would be if it did.

The general rule is that, if an activity involves a hazard that's very likely to cause harm, with serious consequences if it does, that activity is considered high-risk.

Example 1

If you go for a walk, you may sprain an ankle. But most sprains recover within a few weeks if they're rested, so going for a walk would be considered a low-risk activity.

Example 2

If you go skiing, you may fall and break a bone. This would take many weeks to heal, and may cause further complications later on in life. So skiing would be considered higher risk than walking.

Perceptions of risk

Not all risks have the same consequences, e.g. if you chop veg with a sharp knife you risk cutting your finger, but if you go scuba-diving you risk death. You're much more likely to cut your finger during half an hour of chopping than to die during half an hour of scuba-diving. But most people are happier to accept a higher probability of an accident if the consequences are short-lived and fairly minor.

People tend to be more willing to accept a risk if they choose to do something (e.g. go scuba diving), compared to having the risk imposed on them (e.g. having a nuclear power station built next door).

Tip: Risks people choose to take are called 'voluntary risks'. Risks that people are forced to take are called 'imposed risks'.

People's perception of risk (how risky they think something is) isn't always accurate. They tend to view familiar activities as low-risk and unfamiliar activities as high-risk — even if that's not the case. For example, cycling on roads is often high-risk, but many people are happy to do it because it's a familiar activity. Air travel is actually pretty safe, but a lot of people perceive it as high-risk. People may over-estimate the risk of things with long-term or invisible effects.

Reducing risk in investigations

Part of planning an investigation is making sure that it's safe. To make sure your experiment is safe you must identify all the **hazards**. Hazards include:

Tip: You can find out about potential hazards by looking in textbooks, doing some internet research, or asking your teacher.

- Microorganisms: e.g. some bacteria can make you ill.
- Chemicals: e.g. sulfuric acid can burn your skin and alcohols catch fire easily.
- Fire: e.g. an unattended Bunsen burner is a fire hazard.
- Electricity: e.g. faulty electrical equipment could give you a shock.

Once you've identified the hazards you might encounter, you should think of ways of reducing the risks from the hazards.

Figure 1: *Scientists wearing safety goggles to protect their eyes during an experiment.*

Examples

- If you're working with sulfuric acid, wear gloves and safety goggles. This will reduce the risk of the acid coming into contact with your skin and eyes.
- If you're using a Bunsen burner, stand it on a heat-proof mat. This will reduce the risk of starting a fire.

5. Designing Investigations

To be a good scientist you need to know how to design a good experiment.

Making predictions from a hypothesis

Scientists observe things and come up with hypotheses to explain them. To decide whether a **hypothesis** might be correct, you need to do an investigation to gather evidence, which will help support or disprove the hypothesis.
The first step is to use the hypothesis to come up with a **prediction** — a statement about what you think will happen that you can test.

Example

If your hypothesis is "increasing the temperature will increase the rate of an enzyme-controlled reaction", then your prediction might be "an enzyme-controlled reaction carried out at 40 °C will be faster than the same enzyme-controlled reaction carried out at 20 °C".

Once a scientist has come up with a prediction, they'll design an investigation to see if there are patterns or relationships between two variables.
For example, to see if there's a pattern or relationship between the variables 'temperature' and 'time taken for enzyme-controlled reaction to finish'.

Tip: A variable is just something in the experiment that can change.

Repeatable and reproducible results

Results need to be **repeatable** and **reproducible**. Repeatable means that if the same person does an experiment again using the same methods and equipment, they'll get similar results. Reproducible means that if someone else does the experiment, or a different method or piece of equipment is used, the results will be similar. Data that's repeatable and reproducible is **reliable** and scientists are more likely to have confidence in it.

Example

In 1998, a scientist claimed to have found a link between the MMR vaccine (for measles, mumps and rubella) and autism. This meant many parents stopped their children from being vaccinated, leading to a rise in the number of children catching measles. However, the results have never been reproduced. Health authorities have now concluded that the vaccine is safe.

Figure 1: *The MMR vaccine.*

Ensuring the test is valid

Valid results are repeatable, reproducible and answer the original question.

Example

Do power lines cause cancer? — Some studies have found that children who live near overhead power lines are more likely to develop cancer. What they'd actually found was a **correlation** (relationship) between the variables "presence of power lines" and "incidence of cancer". They found that as one changed, so did the other.

But this data isn't enough to say that the power lines cause cancer, as there might be other explanations. For example, power lines are often near busy roads, so the areas tested could contain different levels of pollution. As the studies don't show a definite link they don't answer the original question.

Tip: Peer review (see page 2) is used to make sure that results are valid before they're published.

Tip: See page 18 for more on correlation.

Tip: For the results of an investigation to be valid the investigation must be a fair test.

Ensuring it's a fair test

In a lab experiment you usually change one variable and measure how it affects another variable. To make it a fair test, everything else that could affect the results should stay the same (otherwise you can't tell if the thing you're changing is causing the results or not — the data won't be valid).

Example

You might change only the temperature of an enzyme-controlled reaction and measure how it affects the rate of reaction. You need to keep the pH the same, otherwise you won't know if any change in the rate of reaction is caused by the change in temperature, or the change in pH.

The variable you change is called the **independent variable**. The variable you measure when you change the independent variable is called the **dependent variable**. The variables that you keep the same are called **control variables**.

Example

In the enzyme-controlled reaction example above, temperature is the independent variable, the rate of the reaction is the dependent variable and the control variables are pH, volume and concentration of reactants, etc.

Control experiments and control groups

Tip: Control experiments let you see what happens when you don't change anything at all.

To make sure no other factors are affecting the results, you often include a **control experiment** — an experiment that's kept under the same conditions as the rest of the investigation, but doesn't have anything done to it.

Example

You can investigate antibiotic resistance in bacteria by growing cultures of bacteria on agar plates, then adding paper discs soaked in antibiotic.

If the bacteria are resistant to the antibiotic they will continue to grow. If they aren't resistant a clear patch will appear around the disc where they have died or haven't grown.

A disc that isn't soaked in antibiotic is included to act as a control. This makes sure any result is down to the antibiotic, not the presence of a paper disc.

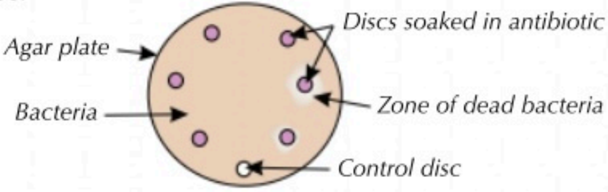


Figure 2: *An investigation into antibiotic resistance.*

Tip: A study is an investigation that doesn't take place in a lab.

It's important that a study is a fair test, just like a lab experiment. It's a lot trickier to control the variables in a study than it is in a lab experiment though. Sometimes you can't control them all, but you can use a **control group** to help. This is a group of whatever you're studying (people, plants, lemmings, etc.) that's kept under the same conditions as the group in the experiment, but doesn't have anything done to it.

Example

If you're studying the effect of pesticides on crop growth, pesticide is applied to one field but not to another field (the control field). Both fields are planted with the same crop, and are in the same area (so they get the same weather conditions).

The control field is there to try and account for variables like the weather, which don't stay the same all the time, but could affect the results.

Tip: A pesticide is a chemical that can be used to kill insects.

Sample size

Data based on small samples isn't as good as data based on large samples. A sample should be representative of the whole population (i.e. it should share as many of the various characteristics in the population as possible) — a small sample can't do that as well.

The bigger the sample size the better, but scientists have to be realistic when choosing how big.

Tip: It's hard to spot anomalous results (see p.13) if your sample size is too small.

Example

If you were studying how lifestyle affects people's weight it'd be great to study everyone in the UK (a huge sample), but it'd take ages and cost a bomb. Studying a thousand people with a mixture of ages, gender and race would be more realistic.

Tip: Samples should be selected randomly. There's an example of how to do this on page 322.

Trial runs

It's a good idea to do a **trial run** (a quick version of your experiment) before you do the proper experiment. Trial runs are used to figure out the range (the upper and lower limits) of independent variable values used in the proper experiment. If you don't get a change in the dependent variable at the upper values in the trial run, you might narrow the range in the proper experiment. But if you still get a big change at the upper values you might increase the range.

Tip: If you don't have time to do a trial run, you could always look at the data other people have got doing a similar experiment and use a range and interval values similar to theirs.

Example

For an experiment into the rate of an enzyme-controlled reaction, you might do a trial run with a temperature range of 10-50 °C. If there was no reaction at the upper end (e.g. 40-50 °C), you might narrow the range to 10-40 °C for the proper experiment.

Trial runs can be used to figure out the appropriate intervals (gaps) between the values too. The intervals can't be too small (otherwise the experiment would take ages), or too big (otherwise you might miss something).

Example

If using 1 °C intervals doesn't give much change in the rate of reaction each time, you might use 5 °C intervals instead, e.g. 10, 15, 20, 25, 30, 35, 40 °C.

Trial runs can also help you figure out whether or not your experiment is repeatable — e.g. if you repeat your experiment three times and the results are all similar, the experiment is repeatable.

Tip: If your repeat results are consistent, you can say your results are repeatable.

6. Collecting Data

Once you've designed your experiment, you need to get on and do it. Here's a guide to making sure the results you collect are good.

Getting good quality results

When you do an experiment you want your results to be **repeatable**, **reproducible** and as **accurate** and **precise** as possible.

Tip: Sometimes, you can work out what result you should get at the end of an experiment (the theoretical result) by doing a bit of maths. If your experiment is accurate there shouldn't be much difference between the theoretical result and the result you actually get.

To check repeatability you need to repeat the readings and check that the results are similar — you should repeat each reading at least three times. To make sure your results are reproducible you can cross check them by taking a second set of readings with another instrument (or a different observer).

Your data also needs to be accurate. Really accurate results are those that are really close to the true answer. The accuracy of your results usually depends on your method — you need to make sure you're measuring the right thing and that you don't miss anything that should be included in the measurements. For example, estimating the amount of gas released from a reaction by counting the bubbles isn't very accurate because you might miss some of the bubbles and they might have different volumes. It's more accurate to measure the volume of gas released using a gas syringe (see p.317).

Tip: For more on means see page 14.

Your data also needs to be precise. Precise results are ones where the data is all really close to the mean (average) of your repeated results (i.e. not spread out).

Example

Look at the data in this table. Data set 1 is more precise than data set 2 because all the data in set 1 is really close to the mean, whereas the data in set 2 is more spread out.

Repeat	Data set 1	Data set 2
1	12	11
2	14	17
3	13	14
Mean	13	14

Choosing the right equipment

When doing an experiment, you need to make sure you're using the right equipment for the job. The measuring equipment you use has to be sensitive enough to measure the changes you're looking for.

Example

If you need to measure changes of 1 cm^3 you need to use a measuring cylinder that can measure in 1 cm^3 steps — it'd be no good trying with one that only measures 10 cm^3 steps, it wouldn't be sensitive enough.

Figure 1: *Different types of glassware used for measuring— make sure you choose the right one before you start an experiment.*

The smallest change a measuring instrument can detect is called its **resolution**. For example, some mass balances have a resolution of 1 g, some have a resolution of 0.1 g, and some are even more sensitive.

Also, equipment needs to be **calibrated** by measuring a known value. If there's a difference between the measured and known value, you can use this to correct the inaccuracy of the equipment.

Example

If a known mass is put on a mass balance, but the reading is a different value, you know that the mass balance has not been calibrated properly.

Tip: Calibration is a way of making sure that a measuring device is measuring things accurately — you get it to measure something you know has a certain value and set the device to say that amount.

Errors

Random errors

The results of an experiment will always vary a bit due to **random errors** — unpredictable differences caused by things like human errors in measuring.

Example

Errors made when reading from a measuring cylinder are random. You have to estimate or round the level when it's between two marks — so sometimes your figure will be a bit above the real one, and sometimes a bit below.

You can reduce the effect of random errors by taking repeat readings and finding the mean. This will make your results more precise.

Tip: If there's no systematic error, then doing repeats and calculating a mean can make your results more accurate.

Systematic errors

If a measurement is wrong by the same amount every time, it's called a **systematic error**.

Example

If you measured from the very end of your ruler instead of from the 0 cm mark every time, all your measurements would be a bit small.

Just to make things more complicated, if a systematic error is caused by using equipment that isn't zeroed properly it's called a **zero error**. You can compensate for some of these errors if you know about them though.

Example

If a mass balance always reads 1 gram before you put anything on it, all your measurements will be 1 gram too heavy. This is a zero error. You can compensate for this by subtracting 1 gram from all your results.

Tip: Repeating the experiment in the exact same way and calculating a mean won't correct a systematic error.

Anomalous results

Sometimes you get a result that doesn't seem to fit in with the rest at all. These results are called **anomalous results** (or outliers).

Example

Look at the data in this table. The entry that has been circled is an anomalous result because it's much larger than any of the other data values.

Experiment	A	B	C	D	E	F
Rate of reaction (cm^3/s)	10.5	11.2	10.8	85.4	10.6	11.1

You should investigate anomalous results and try to work out what happened. If you can work out what happened (e.g. you measured something totally wrong) you can ignore them when processing your results.

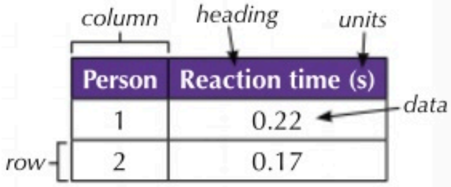
Tip: There are lots of reasons why you might get an anomalous result, but usually they're due to human error rather than anything crazy happening in the experiment.

7. Processing Data

Once you've collected some data, you might need to process it.

Organising data

It's really important that your data is organised. Tables are dead useful for organising data. When you draw a table use a ruler, make sure each column has a heading (including the units) and keep it neat and tidy.


column
heading
units
data
row

Person	Reaction time (s)
1	0.22
2	0.17

Figure 1: *Table showing the time taken to react to a stimulus for two people.*

Tip: If you're recording your data as decimals, make sure you give each value to the same number of decimal places.

Tip: Annoyingly, it's difficult to see any patterns or relationships in detail just from a table. You need to use some kind of graph or chart for that (see pages 16-18).

Processing your data

When you've collected data from an experiment, it's useful to summarise it using a few handy-to-use figures.

Mean and range

When you've done repeats of an experiment you should always calculate the **mean** (a type of average). To do this add together all the data values and divide by the total number of values in the sample.

You might also need to calculate the **range** (how spread out the data is). To do this find the largest number and subtract the smallest number from it.

Example

Look at the data in the table below. The mean and range of the data for each test tube has been calculated.

Test tube	Repeat (g)			Mean (g)	Range (g)
	1	2	3		
A	28	36	32	(28 + 36 + 32) ÷ 3 = 32	36 – 28 = 8
B	47	52	60	(47 + 52 + 60) ÷ 3 = 53	60 – 47 = 13

Median and mode

There are two more types of average, other than the mean, that you might need to calculate. These are the **median** and the **mode**.

- To calculate the median, put all your data in numerical order — the median is the middle value.
- The number that appears most often in a data set is the mode.

Tip: You should ignore anomalous results when calculating the mean, range, median or mode — see page 13 for more on anomalous results.

Example

The results of a study investigating how many minutes it took for people's heart rates to return to resting after sprinting 100 m are shown below:

3, 6, 5, 4, 6, 4, 6, 5, 7

First put the data in numerical order: 3, 4, 4, 5, 5, 6, 6, 6, 7

There are 9 values, so the median is the 5th number, which is **5**.

6 comes up 3 times. None of the other numbers come up more than twice. So the mode is **6**.

Tip: If you have an even number of values, the median is halfway between the middle two values.

Uncertainty

When you repeat a measurement, you often get a slightly different figure each time you do it due to random error. This means that each result has some **uncertainty** to it. The measurements you make will also have some uncertainty in them due to limits in the resolution of the equipment you use. This all means that the mean of a set of results will also have some uncertainty to it. Here's how to calculate the uncertainty of a mean result:

Tip: There's more about errors on page 13.

$$\text{uncertainty} = \text{range} \div 2$$

The larger the range, the less precise your results are and the more uncertainty there will be in your results. Uncertainties are shown using the '±' symbol.

Example

The table below shows the results of a respiration experiment to determine the volume of carbon dioxide produced.

Repeat	1	2	3	mean
Volume of CO_2 produced (cm^3)	20.2	19.8	20.0	20.0

1. The range is: $20.2 - 19.8 = 0.4\ \text{cm}^3$
2. So the uncertainty of the mean is: $\text{range} \div 2 = 0.4 \div 2 = 0.2\ \text{cm}^3$. You'd write this as **$20.0 \pm 0.2\ \text{cm}^3$**

Tip: Since uncertainty affects precision, you'll need to think about it when you come to evaluating your results (see page 22).

Measuring a greater amount of something helps to reduce uncertainty. For example, in a rate of reaction experiment, measuring the amount of product formed over a longer period compared to a shorter period will reduce the percentage uncertainty in your results.

Rounding to significant figures

The first significant figure (s.f) of a number is the first digit that isn't a zero. The second, third and fourth significant figures follow on immediately after the first (even if they're zeros). When you're processing your data you may well want to round any really long numbers to a certain number of significant figures.

Exam Tip
If a question asks you to give your answer to a certain number of significant figures, make sure you do this, or you might not get all the marks.

Example

0.6874976 rounds to **0.69** to **2 s.f.** and to **0.687** to **3 s.f.**

Tip: Remember to write down how many significant figures you've rounded to after your answer.

When you're doing calculations using measurements given to a certain number of significant figures, you should try to give your answer to the lowest number of significant figures that was used in the calculation. If your calculation has multiple steps, only round the final answer, or it won't be as accurate.

Example

For the calculation: $1.2 \div 1.85 = 0.648648648...$

1.2 is given to 2 significant figures. 1.85 is given to 3 significant figures. So the answer should be given to 2 significant figures.

Round the final significant figure (0.648) up to 5: $1.2 \div 1.85 =$ **0.65 (2 s.f.)**

Tip: When rounding a number, if the next digit after the last significant figure you're looking at is less than 5 you should round it down, and if it's 5 or more you should round it up.

The lowest number of significant figures in the calculation is used because the fewer digits a measurement has, the less accurate it is. Your answer can only be as accurate as the least accurate measurement in the calculation.

8. Graphs and Charts

It can often be easier to see trends in data by plotting a graph or chart of your results, rather than by looking at numbers in a table.

Plotting your data on a graph or chart

One of the best ways to present your data after you've processed it is to plot your results on a graph or chart. There are lots of different types you can use.

Bar charts

Bar charts can be used to show categoric, discrete or continuous data.

- **Categoric** data comes in distinct categories, e.g. blood group, eye colour.
- **Discrete** data can only take certain values, with no in-between value, e.g. number of people is discrete because you can't have half a person.
- **Continuous** data is numerical data that can have any value within a range, e.g. length, volume, temperature.

Tip: These golden rules will make sure that your bar chart is clear, easy to read and easy to understand if someone else looks at it.

There are some golden rules you need to follow for drawing bar charts:

- Draw it nice and big (covering at least two-thirds of the graph paper).
- Make sure all the bars are the same width.
- If the data is categoric or discrete, include gaps between the bars. If the data is continuous, the bars should be touching.
- Label both axes and remember to include the units.
- If you've got more than one set of data include a key.
- Give your chart a title explaining what it is showing.

Have a look at Figure 1 for an example of a pretty decent bar chart.

Exam Tip
You could be asked to read a value from a bar chart in the exam. An easy way to do this is to line up a ruler with the top of the bar and follow it across to the *y*-axis (the vertical axis). If there are two sets of data, make sure you use the key to help you identify which bar you need to read the value from.

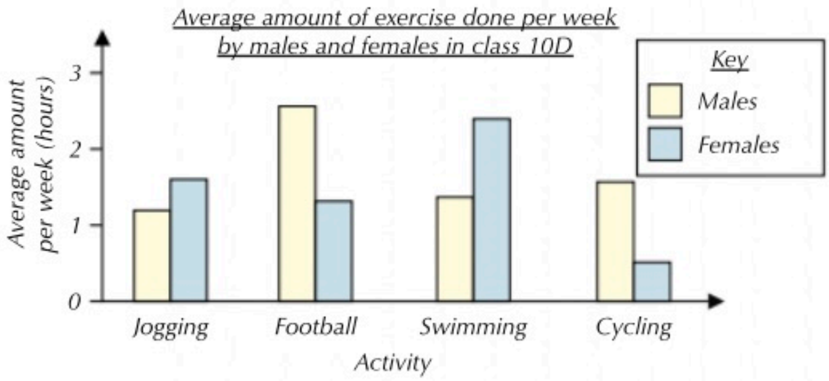
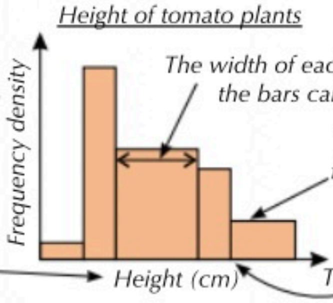


Figure 1: *An example of a bar chart.*

Histograms

Histograms are a useful way of displaying frequency data when the independent variable is **continuous** and the data is grouped together in classes (see next page). Histograms may look like bar charts, but it's the area of the bars that represents the frequency (rather than the height) so the bars can be different widths. The height of each bar is called the frequency density.

Tip: Frequency is just the number of times that something occurs.



The frequency density is plotted on the y-axis.

The width of each bar is the class width — the bars can be different widths.

The area of each bar is the frequency of the class — the class with the largest area has the highest frequency.

The independent variable is plotted on the x-axis.

There are no spaces between the bars.

Figure 2: An example of a histogram.

You calculate the frequency density using this formula:

frequency density = frequency ÷ class width

Example

The table on the right shows the results of a study into variation in pea plant height. The heights of the plants were grouped into four classes.

Height of pea plant (cm)	Frequency
$0 \leq x < 5$	5
$5 \leq x < 10$	14
$10 \leq x < 15$	11
$15 \leq x < 30$	3

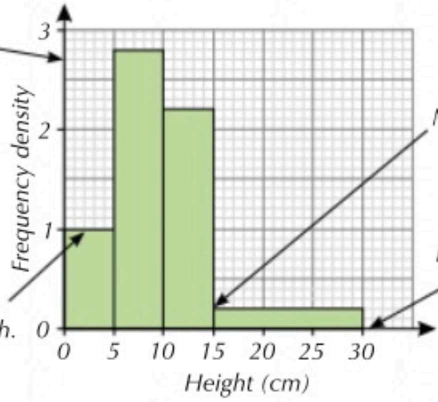
1. To draw a histogram of the data, you first need to work out the width of each class. Write the class width in a new column.

Class width
5 – 0 = **5**
10 – 5 = **5**
15 – 10 = **5**
30 – 15 = **15**

2. Use the formula above to calculate the frequency density for each class. Add a new column to your table for the frequency density.

Frequency density
5 ÷ 5 = **1**
14 ÷ 5 = **2.8**
11 ÷ 5 = **2.2**
3 ÷ 15 = **0.2**

3. Work out a suitable scale for each axis, then plot the histogram. It should look something like this:



Frequency density goes on the y-axis. (So the height of the bars is the frequency density.)

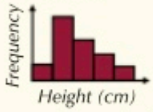
The width of each bar is the class width.

Make sure the bars are touching.

Height (the independent variable) goes on the x-axis.

Tip: Don't be fooled by the height of the bars in a histogram — the tallest bar doesn't always belong to the class with the greatest frequency.

Tip: If all the classes are the same width, you can just plot frequency on the *y*-axis, e.g.



This type of graph is called a frequency diagram.

Tip: This continuous data has been split into classes. $0 \leq x < 5$ means the data in the class is more than or equal to 0 and less than 5.

Tip: The table in the example is a frequency table — it shows how many plants are in each height category.

Tip: You might have to round the frequency density — if so, choose a sensible number of decimal places that will be possible to plot using your graph's scale.

Tip: The width of the whole histogram shows the range of results (how spread out they are).

Tip: You can calculate the frequency of a class from a histogram by rearranging the formula: frequency = frequency density × class width.

Plotting points

If both the independent and dependent variables are **continuous** you should plot points on a graph to display the data. Here are the golden rules for plotting points on graphs:

- Draw it nice and big (covering at least two-thirds of the graph paper).
- Put the independent variable (the thing you change) on the *x*-axis (the horizontal one).
- Put the dependent variable (the thing you measure) on the *y*-axis (the vertical one).
- Label both axes and remember to include the units.
- To plot the points, use a sharp pencil and make a neat little cross.
- Don't join the dots up. If you're asked to draw a line of best fit (or a curve of best fit if your points make a curve), try to draw the line through or as near to as many points as possible, ignoring anomalous results.
- If you've got more than one set of data include a key.
- Give your graph a title explaining what it is showing.

Exam Tip
You could be asked to plot points for a graph in your exam. If so, make sure you follow the golden rules or you could end up losing marks.

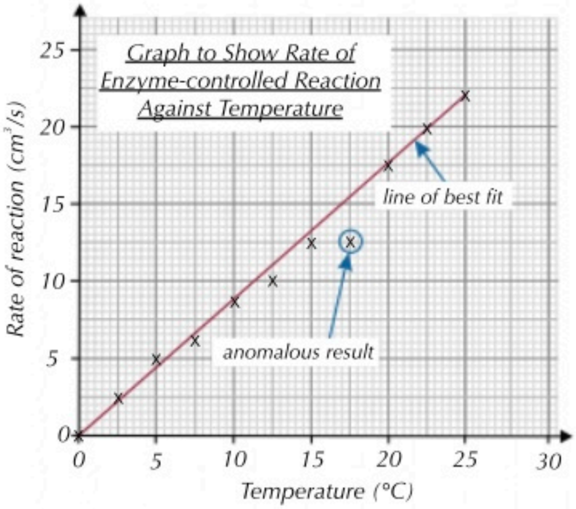


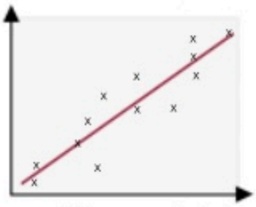
Figure 3: An example of a graph with a line of best fit.

Tip: Use the biggest data values you've got to draw a sensible scale on your axes. Here, the highest rate of reaction is 22 cm^3/s, so it makes sense to label the *y*-axis up to 25 cm^3/s.

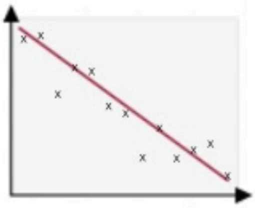
Tip: If you're not in an exam, you can use a computer to plot a graph and draw the line of best fit for you.

Correlations

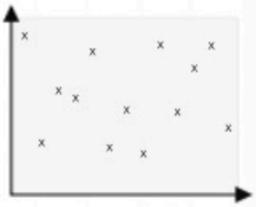
Graphs are used to show the relationship between two variables. Data can show three different types of **correlation** (relationship):



Positive correlation
As one variable increases the other increases.



Inverse (negative) correlation
As one variable increases the other decreases.



No correlation
There's no relationship between the two variables.

Tip: Just because two variables are correlated doesn't mean that the change in one is causing the change in the other. There might be other factors involved, or it may just be down to chance — see pages 21-22 for more.

9. Units

Using the correct units is important when you're drawing graphs or calculating values with a formula. Otherwise your numbers don't really mean anything.

SI units

Lots of different units can be used to describe the same quantity. For example, volume can be given in terms of cubic feet, cubic metres, litres or pints. It would be quite confusing if different scientists used different units to define quantities, as it would be hard to compare people's data. To stop this happening, scientists have come up with a set of standard units, called **SI units**, that all scientists use to measure their data. Figure 1 shows some SI units you'll see in biology:

Tip: SI stands for 'Système International', which is French for 'international system'.

Quantity	SI Base Unit
mass	kilogram, kg
length	metre, m
time	second, s

Figure 1: *Some common SI base units used in biology.*

Scaling prefixes

Quantities come in a huge range of sizes. For example, the volume of a swimming pool might be around 2 000 000 000 cm^3, while the volume of a cup is around 250 cm^3. To make the size of numbers more manageable, larger or smaller units are used. Figure 2 shows the prefixes which can be used in front of units (e.g. metres) to make them bigger or smaller:

prefix	tera (T)	giga (G)	mega (M)	kilo (k)	deci (d)	centi (c)	milli (m)	micro (μ)	nano (n)
multiple of unit	10^{12}	10^{9}	1 000 000 (10^{6})	1000	0.1	0.01	0.001	0.000001 (10^{-6})	10^{-9}

Figure 2: *Scaling prefixes used with units.*

These prefixes are called scaling prefixes and they tell you how much bigger or smaller a unit is than the base unit. So one kilometre is one thousand metres.

Converting between units

To swap from one unit to another, all you need to know is what number you have to divide or multiply by to get from the original unit to the new unit — this is called the conversion factor and is equal to the number of times the smaller unit goes into the larger unit.

- To go from a bigger unit to a smaller unit, you multiply by the conversion factor.
- To go from a smaller unit to a bigger unit, you divide by the conversion factor.

Tip: If you're going from a smaller unit to a larger unit, your number should get smaller.
If you're going from a larger unit to a smaller unit, your number should get larger.
This is a handy way to check you've done the conversion correctly.

Here are some conversions that'll be particularly useful for GCSE biology:

- Mass can have units of kg and g.

$$\begin{tikzcd} \text{kg} \arrow[r, bend left, "\times 1000"] & \text{g} \arrow[l, bend left, "\div 1000"] \end{tikzcd}$$

- Length can have lots of units, including mm, μm and nm.

$$\begin{tikzcd} \text{mm} \arrow[r, bend left, "\times 1000"] & \mu\text{m} \arrow[l, bend left, "\div 1000"] \arrow[r, bend left, "\times 1000"] & \text{nm} \arrow[l, bend left, "\div 1000"] \end{tikzcd}$$

Exam Tip
Being familiar with these common conversions could save you time when it comes to doing calculations in the exams.

- Time can have units of min and s.

$$\begin{tikzcd} \text{min} \arrow[r, bend left, "\times 60"] & \text{s} \arrow[l, bend left, "\div 60"] \end{tikzcd}$$

- Volume can have units of m^3, dm^3 and cm^3.

$$\begin{tikzcd} \text{m}^3 \arrow[r, bend left, "\times 1000"] & \text{dm}^3 \arrow[l, bend left, "\div 1000"] \arrow[r, bend left, "\times 1000"] & \text{cm}^3 \arrow[l, bend left, "\div 1000"] \end{tikzcd}$$

Tip: Volume is also often given in L (litres) or ml (millilitres). To convert, you'll need to remember that 1 ml = 1 cm^3 and so 1 L =1000 cm^3.

Examples

- To go from dm^3 to cm^3, you'd multiply by the conversion factor (which is 1000).

  2 dm^3 is equal to 2 × 1000 = **2000 cm^3**

- To go from grams to kilograms, you'd divide by the conversion factor (which is 1000).

  3400 g is equal to 3400 ÷ 1000 = **3.4 kg**

Units of rate

Rate is a measure of how much something changes over time. For example, a rate of reaction measures how quickly reactants are changed into products. The units of rate are 'units of the quantity that changes / units of time'.

Exam Tip
As well as rates of reaction, you'll be expected to calculate things like rate of water uptake (see p.211).

Example

For an enzyme-controlled reaction that releases a gas as a product (measured in cm^3), the units of rate might be cm^3/s. This can also be written as $cm^3\ s^{-1}$. Both mean 'centimetres cubed per second'.

Tip: The units of time might be different, e.g. they could be in minutes, hours or days.

10. Conclusions and Evaluations

So... you've planned and carried out an amazing experiment, got your data and have processed and presented it in a sensible way. Now it's time to figure out what your data actually tells you, and how much you can trust what it says.

How to draw conclusions

Drawing conclusions might seem pretty straightforward — you just look at your data and say what pattern or relationship you see between the dependent and independent variables.

But you've got to be really careful that your conclusion matches the data you've got and doesn't go any further. You also need to be able to use your results to justify your conclusion (i.e. back up your conclusion with some specific data).

When writing a conclusion you need to refer back to the original hypothesis and say whether the data supports it or not.

Example

The table shows the heights of pea plant seedlings grown for three weeks with different fertilisers.

Fertiliser	Mean growth (mm)
A	13.5
B	19.5
No fertiliser	5.5

You could conclude that fertiliser B makes pea plant seedlings grow taller over a three week period than fertiliser A.

The justification for this conclusion is that over the three week period, fertiliser B made pea plants grow 6 mm more on average than fertiliser A.

You can't conclude that fertiliser B makes any other type of plant grow taller than fertiliser A — the results could be totally different.

The hypothesis for this experiment might have been that adding fertiliser would increase the growth of plants and that different types of fertiliser would affect growth by different amounts. The data supports this hypothesis.

Figure 1: *A pea plant seedling.*

Correlation and causation

If two things are correlated (i.e. there's a relationship between them) it doesn't necessarily mean that a change in one variable is causing the change in the other — this is really important, don't forget it. There are three possible reasons for a correlation:

Tip: Graphs can be useful for seeing whether two variables are correlated (see page 18).

Tip: Causation just means one thing is causing another.

1. Chance

Even though it might seem a bit weird, it's possible that two things show a correlation in a study purely because of chance.

Example

One study might find a correlation between the number of people with breathing problems and the distance they live from a cement factory. But other scientists don't get a correlation when they investigate it — the results of the first study are just a fluke.

Tip: Lots of things are correlated without being directly related. E.g. the level of carbon dioxide (CO_2) in the atmosphere and the amount of obesity have both increased over the last 100 years, but that doesn't mean increased atmospheric CO_2 is causing people to become obese.

2. They're linked by a third variable

A lot of the time it may look as if a change in one variable is causing a change in the other, but it isn't — a third variable links the two things.

Example

There's a correlation between water temperature and shark attacks. This isn't because warm water makes sharks crazy. Instead, they're linked by a third variable — the number of people swimming (more people swim when the water's hotter, and with more people in the water shark attacks increase).

3. Causation

Sometimes a change in one variable does cause a change in the other.

Example

There's a correlation between smoking and lung cancer.
This is because chemicals in tobacco smoke cause lung cancer.

You can only conclude that a correlation is due to a cause if you've controlled all the variables that could be affecting the result. (For the smoking example, this would include age and exposure to other things that cause cancer.)

Evaluation

An evaluation is a critical analysis of the whole investigation. Here you need to comment on the following points about your experiment and the data you gathered:

- **The method**: Was it valid? Did you control all the other variables to make it a fair test?
- **The quality of your results**: Was there enough evidence to reach a valid conclusion? Were the results repeatable, reproducible, accurate and precise?
- **Anomalous results**: Were any of the results anomalous? If there were none then say so. If there were any, try to explain them — were they caused by errors in measurement? Were there any other variables that could have affected the results? You should comment on the level of uncertainty in your results too.

Tip: When you're commenting on the quality of your results, think about things like whether you took enough repeats and whether other people's results were similar to your own.

Once you've thought about these points you can decide how much confidence you have in your conclusion. For example, if your results are repeatable, reproducible, accurate and precise and they back up your conclusion then you can have a high degree of confidence in your conclusion.

You can also suggest any changes to the method that would improve the quality of the results, so that you could have more confidence in your conclusion. For example, you might suggest changing the way you controlled a variable, or increasing the number of measurements you took. Taking more measurements at narrower intervals could give you a more accurate result.

You could also make more predictions based on your conclusion, then further experiments could be carried out to test them.

Tip: When suggesting improvements to the investigation, always make sure that you say why you think this would make the results better.

1. Cell Structure

All living things are made of cells — they're the building blocks of every organism on the planet. But different organisms have different cell structures...

Prokaryotes and eukaryotes

Cells can be either **prokaryotic** or **eukaryotic**. Eukaryotic cells are complex and include all animal and plant cells. Prokaryotic cells are smaller and simpler, e.g. bacteria (see next page).

Eukaryotes are organisms that are made up of eukaryotic cells. A **prokaryote** is a prokaryotic cell (it's a single-celled organism).

Both eukaryotic and prokaryotic cells contain various cell parts called **subcellular structures**. Subcellular structures are also known as organelles.

Animal cells

Most animal cells have the following subcellular structures — make sure you know them all. The parts are labelled in Figure 2.

- **Nucleus** — contains genetic material that controls the activities of the cell. Genetic material is arranged into chromosomes (see p.58).
- **Cytoplasm** — a gel-like substance where most of the chemical reactions happen. It contains enzymes (see p.36) that control these chemical reactions.
- **Cell membrane** — holds the cell together and controls what goes in and out.
- **Mitochondria** — these are where most of the reactions for aerobic respiration take place (see p.270). Respiration transfers energy that the cell needs to work.
- **Ribosomes** — these are involved in protein synthesis (making proteins). The second stage of protein synthesis (called translation — see p.96) takes place here.

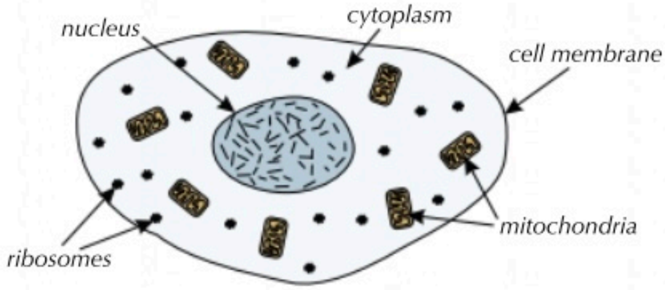


Figure 2: *The structure of a typical animal cell.*

Learning Objective:
- Be able to explain how the subcellular structures of eukaryotic and prokaryotic cells are related to their functions, including:
  - the nucleus, cell membrane, mitochondria and ribosomes in animal cells;
  - the nucleus, cell membrane, cell wall, chloroplasts, mitochondria, vacuole and ribosomes in plant cells;
  - chromosomal DNA, plasmid DNA, cell membrane, ribosomes and flagella in bacteria.

Specification Reference 1.1

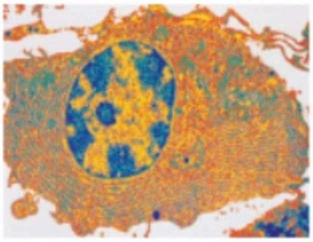


Figure 1: *A human cell seen under a microscope — the blue and yellow oval is the nucleus.*

Tip: A nucleus isn't really blue and yellow. The image in Figure 1 would have been made in black and white — colour has been artificially added to make it easier to see.

Tip: The diagrams on this page and the previous one all show 'typical' cells.
In reality the structure of a cell varies according to what job it does, so most cells won't look exactly like these.

Plant cells

Plant cells usually have all the bits that animal cells have, plus a few extra:

- **Cell wall** — a rigid structure made of cellulose. It supports and strengthens the cell.
- **Large vacuole** — contains cell sap, a weak solution of sugar and salts. It maintains the internal pressure to support the cell.
- **Chloroplasts** — these are where photosynthesis occurs, which makes food for the plant (see page 198). They contain a green substance called **chlorophyll**, which absorbs the light needed for photosynthesis.

The subcellular structures of a typical plant cell are shown in Figure 4.

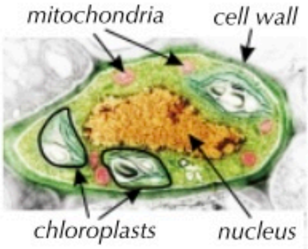

mitochondria
cell wall
chloroplasts
nucleus

Figure 3: *A cross-section of a plant cell seen under a microscope.*

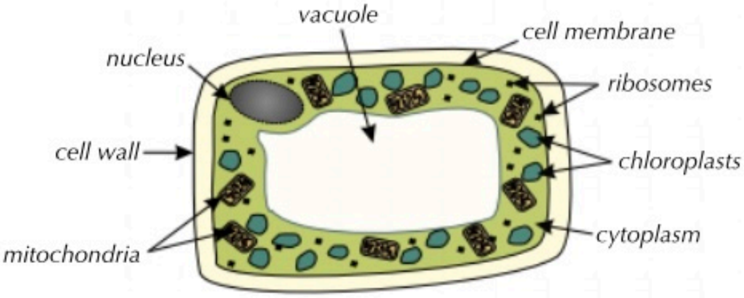

vacuole
cell membrane
nucleus
ribosomes
cell wall
chloroplasts
cytoplasm
mitochondria

Figure 4: *The structure of a typical plant cell.*

Bacterial cells

Bacteria are prokaryotes. A bacterial cell has cytoplasm, containing ribosomes, and a cell membrane surrounded by a cell wall.

The cell doesn't have a 'true' nucleus — instead it has a single circular strand of chromosomal DNA that floats freely in the cytoplasm (see Figure 5). This controls the cell's activities and replication.

Tip: Bacterial cells don't contain any chloroplasts or mitochondria.

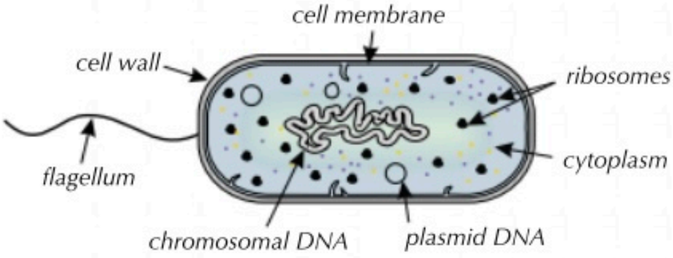

cell membrane
cell wall
ribosomes
flagellum
cytoplasm
chromosomal DNA
plasmid DNA

Figure 5: *The structure of a typical bacterial cell.*

Bacterial cells may also contain one or more small loops of DNA called **plasmids**. These aren't part of the main chromosome. Plasmids contain genes for things like drug resistance, and can be passed between bacteria.

Some bacterial cells also have a **flagellum**. This is a long hair-like structure that rotates to make the bacterium move. It can be used to move the bacterium away from harmful substances like toxins and towards beneficial things like nutrients or oxygen.

Tip: The plural of flagellum is flagella. Some bacteria have more than one flagellum.

Practice Questions — Fact Recall

Q1 Which part of an animal cell controls its activity?

Q2 Where in a cell do most of the reactions involved in aerobic respiration take place?

Q3 What are the ribosomes needed for in a cell?

Q4 a) Name three structures that a plant cell usually has, that an animal cell doesn't.

b) Describe the functions of each of the structures you named in part a).

Q5 What is a plasmid?

Q6 a) What is a flagellum?

b) Give two things that a bacterium might use its flagellum for.

Exam Tip
You need to learn the functions of the subcellular structures, not just their names.

Practice Questions — Application

Q1 The table below contains some information about a typical fungal cell. Fungal cells are eukaryotic. They share some similarities with animal and plant cells but are different to both.

Contains a nucleus	✓
Contains mitochondria	✓
Contains chloroplasts	✗
Has a cell membrane	✓
Has a cell wall	✓

a) Using the information in the table, give one way in which a fungal cell is similar to an animal cell, but different to a plant cell.

b) Using the information in the table, give one way in which a fungal cell is similar to a plant cell, but different to an animal cell.

Tip: Fungal cells make up fungi. Fungi include things like mushrooms and yeast.

2. Specialised Cells

Learning Objectives:

- Be able to describe how specialised cells are adapted to their function, including:
  - sperm cells, and how the acrosome, haploid nucleus, mitochondria and tail make them adapted to their function;
  - egg cells and how nutrients in the cytoplasm, the haploid nucleus and changes in the cell membrane after fertilisation make them adapted to their function;
  - ciliated epithelial cells.

Specification Reference 1.2

Multicellular organisms contain lots of different types of cells — each type does a different job. A cell's structure is related to the job it does, so cell structure can vary.

What is a specialised cell?

A specialised cell is one that performs a specific function. Most cells in an organism are specialised. A cell's structure (e.g. its shape and the parts it contains) helps it to carry out its function — so depending on what job it does, a specialised cell can look very different to the cells you saw on pages 23-24.

You need to learn how the structures of three particular types of specialised cell — **sperm cells**, **egg cells** and **ciliated epithelial cells** — make them adapted to their function.

Sperm cells and egg cells

Sperm cells and egg cells are specialised cells. They are adapted to carry out their functions in sexual reproduction.

During sexual reproduction, the nucleus of an egg cell fuses with the nucleus of a sperm cell to create a fertilised egg (see Figure 1) which then develops into an embryo.

Tip: There's more on sexual reproduction on p.84-85 and p.87-88.

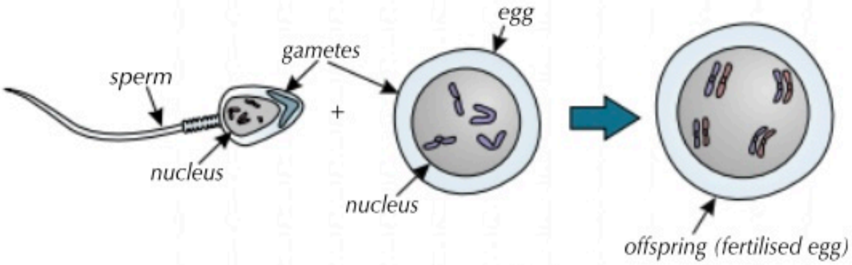


Figure 1: *Diagram showing fertilisation.*

Adaptations of a sperm cell

The function of a sperm is to transport the male DNA to the female DNA in the egg. As a result, a sperm cell has a long tail so it can swim to the egg. It also has lots of mitochondria in its middle section to provide the energy needed to swim this distance. The **acrosome** at the front of the sperm's 'head', stores the enzymes the sperm needs to digest its way through the membrane of the egg cell. A sperm cell also contains a haploid nucleus — there's more on this on the next page. The structure of a sperm cell is shown by Figures 2 and 3.

Tip: Mitochondria (see p.23) provide energy through aerobic respiration (see p.270).

Figure 2: *A microscope image of a sperm cell. It's easy to see the long tail.*

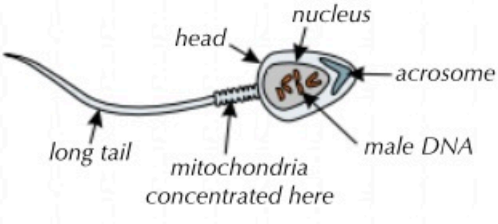


Figure 3: *A sperm cell.*

Adaptations of an egg cell

The main functions of an egg are to carry the female DNA and to nourish the developing embryo in the early stages. To enable it to do this, it contains nutrients in the cytoplasm to feed the embryo. It also has a haploid nucleus (see below). Straight after fertilisation, its membrane changes structure to stop any more sperm getting in. This makes sure the offspring end up with the right amount of DNA.

Haploid nuclei

A sperm cell and an egg cell both have what's called a '**haploid**' nucleus — this is a nucleus that contains half the number of chromosomes that's in a normal body cell. For example, a human sperm cell and a human egg cell each contain 23 chromosomes. A normal human body cell contains 46 chromosomes. This is important as it means that when a sperm cell nucleus combines with an egg cell nucleus at fertilisation, the resulting cell will have the right number of chromosomes.

Tip: The plural of nucleus is nuclei.

Tip: Chromosomes are long coiled up molecules of DNA — the genetic material of a cell. There's more on chromosomes on p.58.

Ciliated epithelial cells

Epithelial cells line the surfaces of organs. Some of them have **cilia** (hair-like structures) on the top surface of the cell (see Figures 4 and 5).

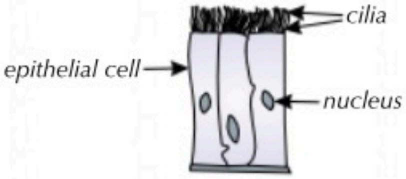


Figure 4: *Ciliated epithelial cells.*

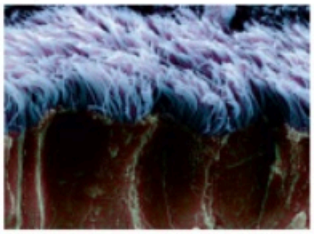


Figure 5: *A microscope image showing ciliated epithelial cells in the airways. The cilia (shown in blue here) are on top of the cells.*

The function of these ciliated epithelial cells is to move substances — the cilia beat to move substances in one direction, along the surface of the tissue.

Example

The lining of the airways contains lots of ciliated epithelial cells. These help to move mucus (and all of the particles from the air that it has trapped) up to the throat so it can be swallowed and doesn't reach the lungs.

Practice Questions — Fact Recall

Q1 The head of a sperm cell contains enzymes that can digest through the membrane of an egg cell. Name the subcellular structure in which these enzymes are stored.

Q2 Give two functions of an egg cell.

Q3 Give two ways in which an egg cell is adapted to help make sure an embryo ends up with the correct amount of DNA.

Practice Question — Application

Q1 Suggest why ciliated epithelial cells usually contain large numbers of mitochondria.

Exam Tip
In the exams, you might get asked to suggest how a specialised cell that you've not come across before is adapted to its function. If so, don't panic — just apply what you've learnt about the specialised cells here, as well as your knowledge of subcellular structures.

3. Microscopy

Microscopy is the study of very small objects (such as cells) using an instrument called a microscope. It's an essential part of biology, really.

Learning Objectives:

- Be able to explain how changes in microscope technology, including electron microscopy, have enabled us to see cell structures and organelles with more clarity and detail than in the past and increased our understanding of the role of subcellular structures.
- Be able to investigate biological specimens using microscopes, including labelled scientific drawings from observations and magnification calculations. (Core Practical)
- H Be able to carry out calculations with numbers written in standard form.
- Be able to demonstrate an understanding of the relationship between quantitative units in relation to cells, including: milli (10^{-3}), micro (10^{-6}), nano (10^{-9}) and pico (10^{-12}).
- Be able to demonstrate an understanding of number, size and scale, including the use of estimations and explain when they should be used.

Specification References
1.3 – 1.6

Microscopes

Microscopes let us see things that we can't see with the naked eye, such as individual cells and their subcellular structures. The microscopy techniques we can use have developed over the years as technology and knowledge have improved. The two types of microscope you need to know about are:

Light microscopes

Light microscopes were invented in the 1590s. They use light and lenses to form an image of a specimen and magnify it (make it look bigger). They let us see individual cells and large subcellular structures, like nuclei and chloroplasts. They can also be used to study living cells.

Electron microscopes

Electron microscopes were invented in the 1930s. They use electrons instead of light to form an image. They have a much higher **magnification** than light microscopes. They also have a higher **resolution**. Resolution is the ability to distinguish between two points, so a higher resolution gives a sharper, clearer image.

Electron microscopes let us see much smaller things in more detail, like the internal structure of mitochondria and chloroplasts. They even let us see tinier things like ribosomes and plasmids. This has given us a greater understanding of how cells work and of the role of subcellular structures within cells. However, electron microscopes can't be used to view living cells.

Using a light microscope

CORE PRACTICAL

You need to know the ins and outs of using a light microscope, including how to prepare your specimen, how to focus the microscope and how to make accurate drawings of what you observe.

Preparing a slide

If you want to look at a specimen (e.g. plant or animal cells) under a light microscope, you need to put it on a microscope slide first. A slide is a strip of clear glass or plastic onto which the specimen is mounted. For example, here's how to prepare a slide to view onion cells:

1. Add a drop of water to the middle of a clean slide. This will secure the specimen in place.
2. Cut up an onion and separate it out into layers. Use tweezers to peel off some epidermal tissue from the bottom of one of the layers.
3. Using the tweezers, place the epidermal tissue into the water on the slide.
4. Add a drop of iodine solution. Iodine solution is a stain. Stains are used to add colour to objects in a cell, making them easier to see. Different stains can be used to highlight different things. E.g. methylene blue can be used to stain DNA and eosin can be used to stain the cytoplasm.

Tip: Make sure you carry out a risk assessment so that you're aware of any hazards, particularly for any stains you're using, before you start preparing your slide.

5. Place a cover slip (a square of thin, transparent plastic or glass) upright on the slide, next to the water droplet. Then, holding it at an angle with a mounted needle, carefully lower it so it covers the specimen. Try not to get any air bubbles under there — they'll obstruct your view of the specimen. Steps 1-5 are shown in Figure 1.

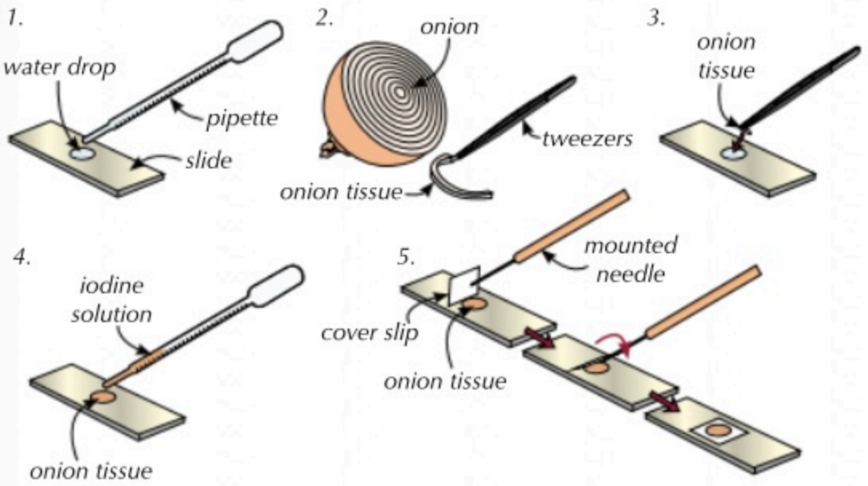

1.
water drop
pipette
slide
2.
onion
tweezers
onion tissue
3.
onion tissue
4.
iodine solution
onion tissue
5.
mounted needle
cover slip
onion tissue

Figure 1: *Preparation of a microscope slide.*

Tip: In light microscopes, the beam of light passes through the object being viewed — so the specimen needs to be thin enough to let light through it (like onion epidermal tissue). An image is produced because some parts of the object absorb more light than others. If the object being viewed is completely transparent, the whole thing looks white because the light rays just pass straight through. To get round this, stains are used to highlight parts of the object, making them more visible.

Observing the specimen

You need to know how to set up and use a light microscope (see Figure 2) to observe your prepared slide:

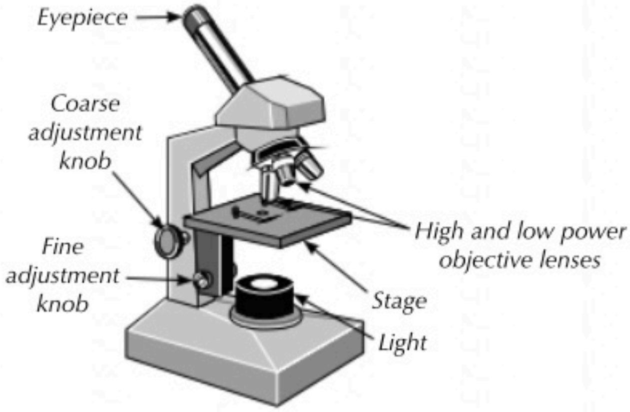

Eyepiece
Coarse adjustment knob
Fine adjustment knob
High and low power objective lenses
Stage
Light

Figure 2: *A light microscope.*

1. Start by clipping the slide you've prepared onto the stage.
2. Select the lowest-powered objective lens (i.e. the one that produces the lowest magnification).
3. Use the coarse adjustment knob to move the stage up to just below the objective lens.
4. Look down the eyepiece. Use the coarse adjustment knob to move the stage downwards until the image is roughly in focus.
5. Adjust the focus with the fine adjustment knob, until you get a clear image of what's on the slide.
6. If you need to see the slide with greater magnification, swap to a higher-powered objective lens and refocus.

Tip: Don't use the eyepiece while you're moving the stage up with the coarse adjustment knob, as you could cause the lens and stage to collide.

Tip: Before focusing on your specimen, you can measure the field of view (the circular area that's visible under the microscope). This will allow you to estimate the size of your specimen. See page 320 for how to do this.

Drawing observations

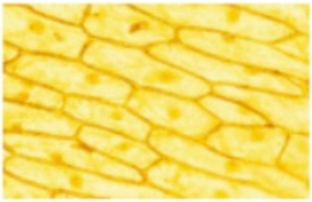


Figure 3: *Onion cells stained with iodine, viewed under × 400 magnification.*

When making a drawing of your specimen from under the microscope, make sure you use a pencil with a sharp point and that you draw with clear, unbroken lines. Your drawing should not include any colouring or shading. If you are drawing cells, the subcellular structures should be drawn in proportion (the correct sizes relative to each other). If you're asked to make your drawing in a certain amount of space (e.g. on a worksheet), it needs to take up at least half of the space available.

You also need to include a title of what you were observing and label the important features of your drawing (e.g. nucleus, chloroplasts) using straight, uncrossed lines. Finally, you need to include the magnification your specimen was viewed under and a scale.

Exam Tip
Make sure you know what all the subcellular structures you learnt about on pages 23-24 look like — it will make it easier to identify them in microscope images.

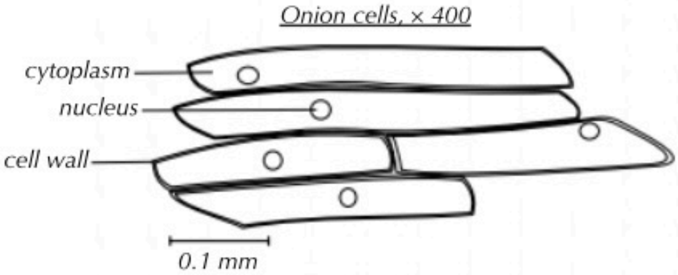


Figure 4: *A drawing of onion cells as viewed under a light microscope.*

Magnification

Magnification is how much bigger the image is than the real object that you're looking at. If you know the power of the microscope lenses used to view a specimen, you can work out the total magnification of the image using this simple formula:

$$\text{total magnification} = \begin{matrix}\text{eyepiece lens}\\ \text{magnification}\end{matrix} \times \begin{matrix}\text{objective lens}\\ \text{magnification}\end{matrix}$$

Example

If your specimen was viewed with an eyepiece lens magnification of × 10 and an objective lens magnification of × 40, the total magnification of your image is:

10 × 40 = **× 400**.

If you don't know which lenses were used, you can still work out the magnification as long as you can measure the image and you know the real size of the specimen. This is the formula you need:

$$\text{magnification} = \frac{\text{image size}}{\text{real size}}$$

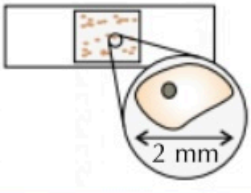
Exam Tip
Make sure you learn these two formulas for your exams.

Example

If you have a magnified image that's 2 mm wide and your specimen is 0.02 mm wide the magnification is:

$$\text{magnification} = \frac{\text{image size}}{\text{real size}}$$

$$= \frac{2}{0.02} = \mathbf{\times\ 100}$$



Tip: Both the image size and the real size should have the same units. If they don't, you'll need to convert them first (see next page).

If you want to work out the image size or the real size of the object, you have to rearrange the equation.

Example

Calculating image size

If your specimen is 0.3 mm wide and the magnification of the microscope is × 50, then the size of the image is:

$$\text{image size} = \text{magnification} \times \text{real size}$$

$$= 50 \times 0.3 = \mathbf{15\ mm}$$

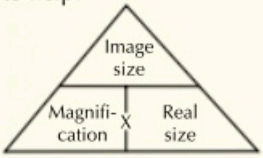
Calculating the real size of an object

If you have a magnified image that's 10 mm wide and the magnification is × 400, then the real size of the specimen you're looking at is:

$$\text{real size} = \frac{\text{image size}}{\text{magnification}} = \frac{10}{400} = \mathbf{0.025\ mm}$$

Exam Tip

If you find rearranging formulas hard you can use a formula triangle to help:



All you do is put your finger over the one you want and read off the formula. E.g. if you want the real size of the object, you put your finger over that and it leaves behind image size ÷ magnification.

Microscopes are used to look at tiny objects, so it's sometimes useful to write the real size of a specimen in standard form. This is where you change very big or small numbers with lots of zeros into something more manageable, e.g. 0.000017 can be written 1.7×10^{-5}. If you're sitting a higher paper, you might need to carry out magnification calculations that involve standard form.

Example **Higher**

A specimen is 5×10^{-3} mm wide. A magnified image of the specimen is 2 mm wide. Calculate the magnification it was viewed under.

If you've got a scientific calculator, you can put standard form numbers into it using the 'EXP' or the or the '×10ˣ' button. So to enter 5×10^{-3}, press 5, then 'EXP' or '×10ˣ', then –3. The calculation is:

$$\text{magnification} = \frac{\text{image size}}{\text{real size}} = \frac{2}{5 \times 10^{-3}} = \mathbf{\times\ 400}$$

With an ordinary calculator, you'll need to write the values out in full. The power of 10 is negative, so 5×10^{-3} must be a small number (less than 1). The power is –3, so the decimal point moves 3 places:

$$0005.0 \times 10^{-3} \longrightarrow 0.005$$

The calculation is: $\frac{2}{0.005} = \mathbf{\times\ 400}$

Tip: There's more on using standard form on pages 324-325.

Converting between units

Tip: There's more on converting units on pages 19-20.

When you're calculating magnification you need to make sure that all measurements have the same units, e.g. all in millimetres. When dealing with microscopes these units can get pretty tiny. The table below shows the units you need to know and how to convert between them:

To convert	Unit	In standard form	To convert
× 1000	Millimetre (mm)	$\times 10^{-3}$ m	÷ 1000
× 1000	Micrometre (µm)	$\times 10^{-6}$ m	÷ 1000
× 1000	Nanometre (nm)	$\times 10^{-9}$ m	÷ 1000
	Picometre (pm)	$\times 10^{-12}$ m	

Tip: So 1 pm = 0.000000000001 m. (That's tiny!)

Examples

- To convert from a smaller unit to a bigger unit you have to divide. So to convert 5 micrometres to millimetres you divide 5 by 1000. 5 ÷ 1000 = **0.005 mm**
- To go from a bigger unit to a smaller unit you have to multiply. So to convert 0.025 micrometres to nanometres you multiply 0.025 by 1000. 0.025 × 1000 = **25 nm**
- If you have a specimen that's 5 µm wide and an image that's 5 mm wide, you need to put both measurements in the same units before you can work out the magnification using the formula:

$$5 \text{ mm} = 5 \times 1000 = 5000 \text{ µm}$$

$$\text{magnification} = \frac{\text{image size}}{\text{real size}} = \frac{5000}{5} = \mathbf{\times\ 1000}$$

Tip: It doesn't matter which units you choose to convert to. In the calculation on the right, if you converted 5 µm to mm (5 ÷ 1000 = 0.005 µm) instead, you'd get the same answer of × 1000 magnification.

Estimating size and area of cell structures

You can estimate the size of a subcellular structure by comparing its size to that of the cell.

Tip: Estimates can come in handy if you don't have a small enough scale to measure something accurately.

Tip: You can estimate the size of a cell by comparing its size to the size of the field of view. See page 320.

Example

Figure 5 shows a cheek cell.

Estimate the width of the nucleus of the cell.

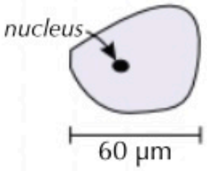
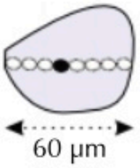


Figure 5: *Cheek cell with scale.*

1. Estimate the number of times that the nucleus could fit across the width of the cell.



The nucleus would fit across the cell about 8 times.

2. Divide the width of the cell by the number of times the nucleus would fit across it.

width of nucleus = 60 µm ÷ 8 = **7.5 µm**

You can estimate the area of a subcellular structure by comparing it to a regular shape.

Example

Figure 6 shows a diagram of a mitochondrion measured under an electron microscope.

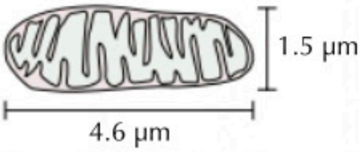


Figure 6: *A mitochondrion.*

The shape of the mitochondrion is close to that of a rectangle.

So to estimate its area, use the formula for the area of a rectangle:
area = length × width

$$\text{Area} = 4.6\ \mu\text{m} \times 1.5\ \mu\text{m} = \mathbf{6.9\ \mu m^2}$$

Exam Tip
In the exam, you could be given a photomicrograph (a picture taken down a light microscope) of a cell and its subcellular structures rather than a diagram. You can estimate the size of the subcellular structures in a photomicrograph in the same way.

Tip: Don't forget to include the units of area in your answer.

Estimating can also help you to check that your answer is correct. To estimate an answer, round the numbers so you can do the maths in your head.

Example

Say you know the real size of a specimen is 21.5 μm and the image size is 9800 μm. To get an estimate of the magnification used, round both numbers to 1 significant figure (see p.15) and do 10 000 ÷ 20 = × 500.

Practice Questions — Fact Recall

Q1 Why can an electron microscope be used to look at smaller objects than a light microscope?

Q2 Why are stains used when preparing microscope slides?

Q3 Describe the steps you would take to obtain a clear image of a specimen on a microscope slide.

Q4 What is 1 nanometre in metres? Give your answer in standard form.

Practice Questions — Application

Q1 Calculate the total magnification of an image viewed with a × 15 eyepiece lens and a × 40 objective lens.

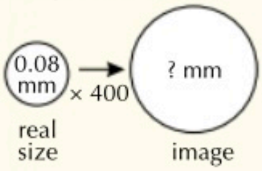
Q2 A bacterial cell is 0.002 mm long. A magnified image of the cell is 18 mm long. What is the magnification of the image?

Q3 A plant cell is 0.08 mm wide. It is examined under a × 400 microscope lens. Calculate the width of the magnified image.

Q4 A specimen is observed under × 1500 magnification. The magnified image is 10.5 mm wide. What is the real width of the specimen? Give your answer in μm.

Q5 A ribosome is 2×10^{-5} mm wide. In an electron microscope image, it is 900 μm wide. What is the magnification of the image?

Tip: If it helps you to work out what size you're looking for, you could draw a diagram of what the question is describing. So for Q2 it might be like this:



Topic 1a Checklist — Make sure you know...

Cell Structure

☐ That animal and plant cells are eukaryotic cells, which make up eukaryotic organisms, and that bacterial cells are prokaryotic cells.

☐ That most animal cells have: a nucleus (which contains the genetic material that controls the activities of a cell), cytoplasm (where most chemical reactions happen), a cell membrane (which controls what goes in and out of the cell), mitochondria (where most of the reactions for aerobic respiration happen), and ribosomes (which are involved in protein synthesis).

☐ That a typical plant cell has all the same parts as an animal cell, plus a cell wall made of cellulose (which supports and strengthens the cell) a large vacuole containing cell sap (which maintains the internal pressure of the cell) and chloroplasts (where photosynthesis occurs).

☐ That a bacterial cell has ribosomes, a cell membrane and a cell wall, and that its genetic material is a single loop of chromosomal DNA found in the cytoplasm (rather than in a nucleus) and potentially one or more plasmids (small rings of DNA). It may also have a flagellum (which rotates to move the cell).

Specialised Cells

☐ That specialised cells are adapted to carry out their functions, and that their adaptations include things like their shape and their subcellular structures.

☐ That the function of a sperm cell is to carry the male DNA to the female DNA during sexual reproduction and how the sperm cell's tail, mitochondria, acrosome and haploid nucleus help it to do this.

☐ That the function of an egg cell is to carry the female DNA during sexual reproduction and to nourish the developing embryo in its early stages, and how nutrients in its cytoplasm, changes to the cell membrane after fertilisation and a haploid nucleus help the egg cell to do this.

☐ That ciliated epithelial cells have cilia (hair-like structures) which beat to move substances along the surface of the epithelial cells.

Microscopy

☐ That microscopy techniques have developed over time due to improving technology.

☐ That electron microscopes can produce images with a higher magnification and resolution than light microscopes, which has allowed us to see subcellular structures in more detail and increased our understanding of their roles.

☐ How to prepare a slide containing a biological specimen and use a light microscope to observe it, how to produce a scientific drawing of your observations, and how to use the formulas: total magnification = eyepiece lens magnification × objective lens magnification and magnification = image size ÷ real size (Core Practical).

☐ The relationship between the units millimetres (1×10^{-3} m), micrometres (1×10^{-6} m), nanometres (1×10^{-9} m) and picometres (1×10^{-12} m) and how to convert between these units.

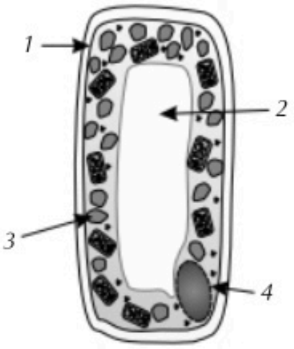
☐ **H** How to carry out magnification calculations with numbers written in standard form.

☐ How estimations can be used when working with cells and why they might be used.

Exam-style Questions

1 **Figure 1** shows a palisade cell from a plant.

Figure 1



(a) Look at the structures labelled 1-4 in **Figure 1**.
Which of the following options gives the correct labels for these structures?

A 1 — vacuole, 2 — nucleus, 3 — chloroplast, 4 — cell membrane

B 1 — nucleus, 2 — chloroplast, 3 — cell membrane, 4 — vacuole

C 1 — cell membrane, 2 — vacuole, 3 — chloroplast, 4 — nucleus

D 1 — cell membrane, 2 — nucleus, 3 — chloroplast, 4 — vacuole

(1 mark)

(b) Is a palisade cell an example of a eukaryotic cell or a prokaryotic cell?
Give a reason for your answer that refers to the cell's structure.

(1 mark)

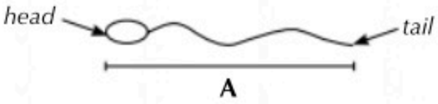
(c) Palisade cells are specialised cells. They are the main site of photosynthesis in a plant and are found grouped together near the top of a leaf.

Suggest **one** subcellular structure that is found in greater numbers in a palisade cell than in other plant cells.

(1 mark)

2 **Figure 2** is a scale drawing of sperm cell viewed under a light microscope.

Figure 2



(a) How does the sperm cell's tail make the cell well adapted to its function?

(1 mark)

A is the image length. The real length of the sperm cell is 55 μm.

(b) Calculate the magnification that the sperm cell was viewed under.

(3 marks)

(c) Use **Figure 2** to estimate the length of the sperm cell's head.

(2 marks)

1. Enzymes

Enzymes are essential. There are loads of different types in the body. They play an important role in speeding up chemical reactions in your insides.

Learning Objectives:

- Be able to explain the mechanism of enzyme action including the active site and enzyme specificity.
- Be able to explain how enzymes can be denatured due to changes in the shape of the active site.
- Be able to explain the effects of temperature, substrate concentration and pH on enzyme activity.

Specification References 1.7 – 1.9

Enzymes

Living things have thousands of different chemical reactions going on inside them all the time — most are useful (you need them to stay alive) but some aren't. The useful reactions need to be carefully controlled — to get the right amounts of substances.

You can usually make a reaction happen more quickly by raising the temperature. This would speed up the useful reactions but also the unwanted ones too... not good. There's also a limit to how far you can raise the temperature inside a living creature before its cells start getting damaged.

So... living things produce enzymes that act as **biological catalysts**. Enzymes reduce the need for high temperatures and we only have enzymes to speed up the useful chemical reactions in the body.

A **catalyst** is a substance which increases the speed of a reaction, without being changed or used up in the reaction.

Enzymes are all large proteins and all proteins are made up of chains of amino acids (see page 93). These chains are folded into unique shapes, which enzymes need to do their jobs (see below).

Active sites

Tip: The substance that an enzyme acts on is called the substrate.

Tip: Enzymes are said to have a "high specificity" for their substrate.

Chemical reactions usually involve things either being split apart or joined together. Every enzyme has an **active site** with a unique shape that fits onto the substance involved in a reaction. Enzymes are really picky — they usually only catalyse one specific reaction. This is because, for the enzyme to work, the substrate has to fit into its active site. If the substrate doesn't match the enzyme's active site, then the reaction won't be catalysed.

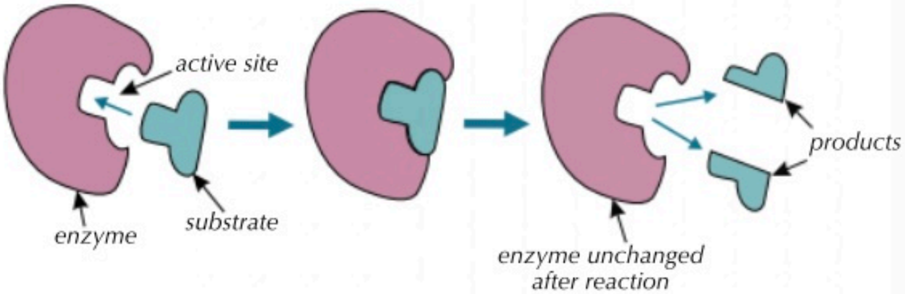


Figure 1: *Diagram to show how an enzyme works.*

Figure 1 (on the previous page) shows the 'lock and key' model of enzyme action. It is so called because the substrate fits into the enzyme like a key fits into a lock.

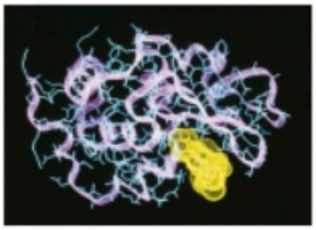


Figure 2: *Computer model of an enzyme bound to a substrate (yellow).*

Optimum conditions for enzymes

Enzymes need the right conditions, such as the right temperature, substrate concentration and pH for them to work best — these are called optimum conditions.

Temperature

Changing the temperature changes the rate of an enzyme-catalysed reaction. As with any reaction, a higher temperature increases the rate at first. But if it gets too hot, some of the bonds holding the enzyme together break. This changes the shape of the enzyme's active site, so the substrate won't fit any more. The enzyme is said to be **denatured**.

Therefore enzymes have a temperature at which they are most active — this is called the optimum temperature (see Figure 3). Enzymes in the human body normally work best at around 37 °C.

Tip: Increasing the temperature increases the rate of a reaction because the reactants have more energy, so they move about more, and collide with each other more often.

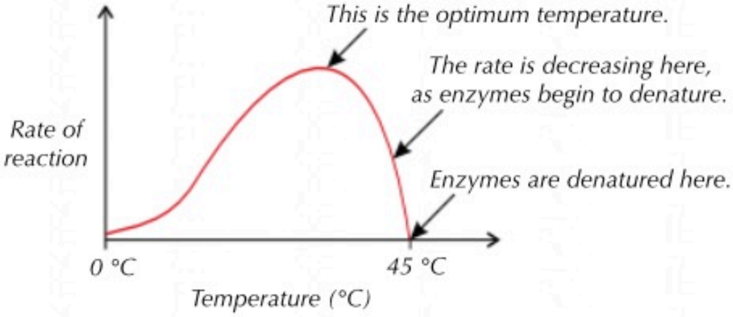


Figure 3: *Graph to show how temperature affects enzyme action.*

Tip: As well as having different optimum temperatures, enzymes denature at different temperatures too. Most human enzymes denature at around 45 °C.

Substrate concentration

Substrate concentration also affects the rate of reaction — the higher the substrate concentration, the faster the reaction. This is because it's more likely that the enzyme will meet up and react with a substrate molecule.

This is only true up to a point though. After that, there are so many substrate molecules that the enzymes have about as much as they can cope with (all the active sites are full), and adding more makes no difference (see Figure 4).

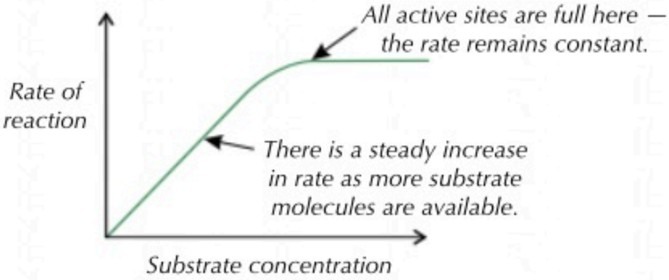


Figure 4: *Graph to show how substrate concentration affects enzyme action.*

Tip: The active site can only catalyse one reaction at a time. Once all of the active sites are full, increasing the amount of substrate has no effect on the rate — there are no available enzymes to catalyse further reactions. The point where increasing the substrate concentration has no effect on the rate will depend on the number of enzymes around.

Tip: A low pH means that an environment is acidic. A high pH means that it is alkaline.

pH

The pH also affects enzymes. If it's too high or too low, the pH interferes with the bonds holding the enzyme together. This changes the shape of the active site and denatures the enzyme.

All enzymes have a pH that they work best at — this is called the optimum pH (see Figure 5).

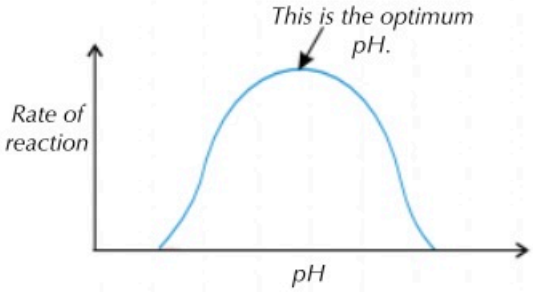


Figure 5: *Graph to show how pH affects enzyme action.*

The optimum pH is different for different enzymes, depending on where they work. For many enzymes it's neutral pH 7, but not always.

Example

Pepsin is an enzyme used to break down proteins in the stomach. It works best at pH 2, which means it's well-suited to the acidic conditions in the stomach.

Practice Questions — Fact Recall

Q1 Why can enzymes be described as catalysts?

Q2 What is the name of the part of an enzyme that binds to the substrate?

Q3 True or false? All enzymes work best at pH 7.

Practice Question — Application

Tip: Respiration is the process of breaking down glucose, which transfers energy. There's loads more about it on pages 270-272.

Q1 Hexokinase is an enzyme found in the human body that's involved in respiration. It catalyses this reaction:

$$\text{glucose} \xrightarrow{\text{hexokinase}} \text{substance A}$$

Enzymes in the human body work best at 37 °C.

A scientist heats up hexokinase to 50 °C and adds it to some glucose. Suggest the effect this will have on the rate of the reaction compared to if the reaction was at 37 °C. Explain your answer.

2. Investigating Enzymatic Reactions

You need to know how to investigate the effect of pH on the rate of the reaction catalysed by an enzyme. Read on for more.

Investigating the effect of pH on amylase

CORE PRACTICAL

The enzyme **amylase** catalyses the breakdown of starch to maltose. It's easy to detect starch using iodine solution — if starch is present, the iodine solution will change from browny-orange to blue-black. This is how you can investigate how pH affects amylase activity:

1. Put a drop of iodine solution into every well of a spotting tile.
2. Place a Bunsen burner on a heat-proof mat, and a tripod and gauze over the Bunsen burner. Put a beaker of water on top of the tripod and heat the water until it reaches the optimum temperature of the amylase you are using. (Use a thermometer to measure the temperature.) Try to keep the temperature of the water constant throughout the experiment.
3. Use a syringe to add 3 cm^3 of amylase solution and 1 cm^3 of a buffer solution with a pH of 5 to a boiling tube. Using test tube holders, put the boiling tube into the beaker of water and wait for five minutes.
4. Next, use a different syringe to add 3 cm^3 of a starch solution to the boiling tube.
5. Immediately mix the contents of the boiling tube and start a stop clock.
6. Use continuous sampling to record how long it takes for the amylase to break down all of the starch. To do this, use a dropping pipette to take a fresh sample from the boiling tube every thirty seconds and put a drop into a well on the spotting tile. When the iodine solution remains browny-orange, starch is no longer present.
7. Repeat the whole experiment with buffer solutions of different pH values to see how pH affects the time taken for the starch to be broken down.
8. Remember to control any variables each time you repeat the experiment to make it a fair test. Variables that need controlling include the concentration and volume of the amylase and starch solutions and the temperature of the reaction mixture. See p.10 for more on fair tests.

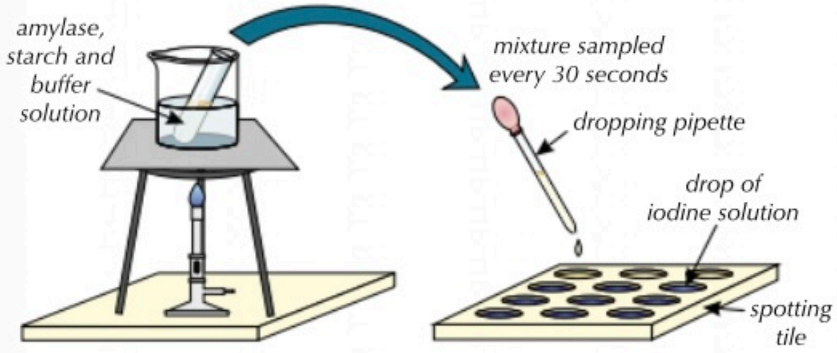

amylase, starch and buffer solution
mixture sampled every 30 seconds
dropping pipette
drop of iodine solution
spotting tile

Figure 1: *Apparatus for investigating the breakdown of starch.*

Learning Objectives:

- Be able to investigate the effect of pH on enzyme activity. (Core Practical).
- Be able to understand rate calculations for enzyme activity.

Specification References 1.10, 1.11

Tip: Don't forget to do a risk assessment before you do this experiment. You should always take basic safety precautions like wearing goggles and a lab coat.

Tip: Instead of using the Bunsen burner and beaker of water, you could set an electric water bath to control the temperature. See page 319 for more on water baths.

Tip: You should repeat the experiment at least three times at each pH and work out the mean time taken for the starch to break down.

Tip: See page 44 for more on testing for starch using iodine.

Tip: You could use a pH meter to accurately measure the pH of your solutions.

Calculating the rate of a reaction

It's often useful to calculate the rate of reaction after an experiment. Rate is a measure of how much something changes over time.

Tip: You could also use the formula '1/time' but '1000/time' will give you a bigger number that is easier to plot on a graph.

For the experiment on the previous page, you can calculate the rate of reaction using this formula:

$$\text{Rate} = \frac{1000}{\text{time}}$$

The units are s^{-1} since rate is given per unit of time.

Example

At pH 6, the time taken for amylase to break down all of the starch in a solution was 90 seconds. So the rate of the reaction = 1000 ÷ 90 = **11 s^{-1}**

If an experiment measures how much something changes over time, you calculate the rate of reaction by dividing the amount that it has changed by the time taken.

Example

The enzyme catalase catalyses the breakdown of hydrogen peroxide into water and oxygen. During an investigation into the activity of catalase, 24 cm^3 of oxygen was released in 50 seconds (s). Calculate the rate of the reaction. Write your answer in cm^3 s^{-1}

Amount of product formed = change = 24 cm^3

Rate of reaction = change ÷ time
= 24 cm^3 ÷ 50 s
= **0.48 cm^3 s^{-1}**

Tip: cm^3 s^{-1} means centimetres cubed per second. It means the same as cm^3/s.

Practice Question — Application

Q1 A group of students were investigating the effect of pH on the rate of starch breakdown by the enzyme amylase. They mixed the enzyme and starch in a boiling tube, then every 10 seconds added a drop of the mixture to a well on a spotting tile containing iodine solution. They timed how long it took for all of the starch to be broken down.

a) What could the students have used to control the pH level of the starch and enzyme mixture?

b) How would the students know when all of the starch had been broken down?

c) It took 120 seconds for all of the starch to be broken down. Calculate the rate of the reaction. Give your answer in s^{-1}.

3. Enzymes in Breakdown and Synthesis

Organisms need to be able to break down large molecules and build them back up again. Lots of enzymes are needed to catalyse these reactions.

Enzymes in breakdown reactions

Carbohydrates, proteins and lipids are big molecules, which are essential for life. Organisms need to be able to break them down into their smaller components, so they can be used for growth and other life processes. These breakdown reactions are catalysed by enzymes.

Examples

- Many of the molecules in the food we eat are too big to pass through the walls of our digestive system, so digestive enzymes break them down into smaller, soluble molecules. These can pass easily through the walls of the digestive system, allowing them to be absorbed into the bloodstream. They can then pass into cells to be used by the body.
- Plants store energy in the form of starch (a carbohydrate). When plants need energy, enzymes break down the starch into smaller molecules (sugars). These can then be respired to transfer energy to be used by the cells (see p.270).

Different types of enzymes catalyse the breakdown of carbohydrates, proteins and lipids.

Carbohydrases

Carbohydrases convert carbohydrates into simple sugars. Amylase is an example of a carbohydrase. It breaks down starch — see Figure 1.

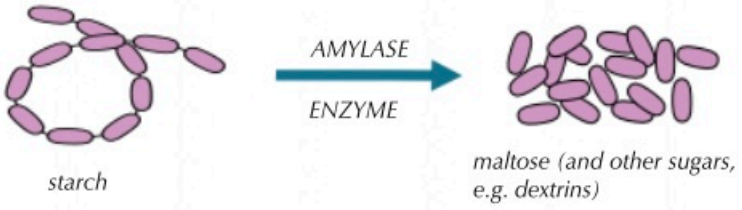


Figure 1: *Diagram to show the breakdown of starch by amylase.*

Proteases

Protease enzymes catalyse the conversion of proteins into amino acids — see Figure 2.

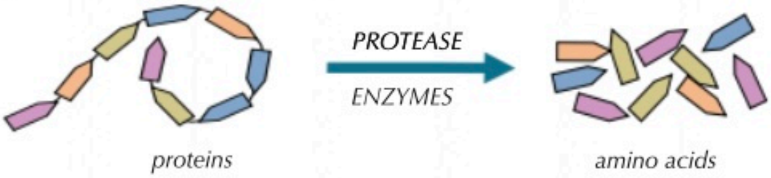


Figure 2: *Diagram to show the breakdown of proteins by proteases.*

Learning Objective:

- Be able to explain the importance of enzymes as biological catalysts in the synthesis of carbohydrates, proteins and lipids and their breakdown into sugars, amino acids and fatty acids and glycerol.

Specification Reference 1.12

Tip: Lipids are fats and oils.

Tip: Carbohydrates, lipids and proteins are all biological molecules — this means they're molecules found in living organisms.

Exam Tip
You need to learn the types of molecules that carbohydrates, proteins and lipids are broken down into.

Tip: When lipids are broken down, the fatty acids will lower the pH of the solution they are in — this is because they're acidic. When proteins are broken down into amino acids, the same thing happens.

Tip: Carbohydrase enzymes break down carbohydrates. Protease enzymes break down proteins. Lipase enzymes break down lipids.

Lipases

Lipase enzymes catalyse the conversion of lipids into glycerol and fatty acids — see Figure 3.

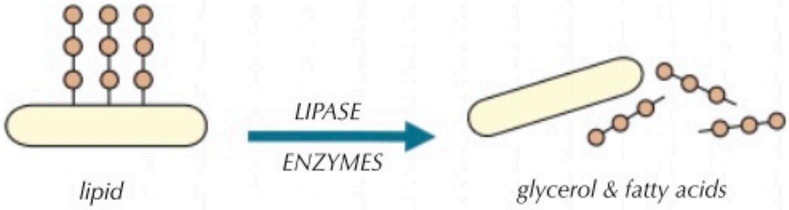


Figure 3: *Diagram to show the breakdown of lipids by lipases.*

Enzymes in synthesis reactions

Organisms also need to be able to synthesise carbohydrates, proteins and lipids from their smaller components. Again, enzymes are used to catalyse the reactions involved. These enzymes are different to the ones used in breakdown reactions.

Carbohydrates can be synthesised by joining together simple sugars.

Example

Glycogen synthase is an enzyme that joins together lots of chains of glucose molecules to make glycogen (a molecule used to store energy in animals).

Proteins are made by joining amino acids together (see page 93). Enzymes catalyse the reactions needed to do this. Lots of enzymes are also involved in the synthesis of lipids from fatty acids and glycerol.

Practice Questions — Fact Recall

Q1 True or false? Digestive enzymes build small molecules up into larger molecules.

Q2 a) Name the type of enzyme that catalyses the breakdown of lipids.

b) What types of molecules are lipids broken down to produce?

Practice Question — Application

Q1 A protease solution is mixed with a protein solution. Every ten minutes, a sample of the solution is taken and mixed with ninhydrin. Ninhydrin is a yellowish compound which turns a deep-purple colour when reacted with amino acids.

Describe how you would expect the colour of the samples to change over the course of the experiment. Explain your answer.

4. Testing for Biological Molecules

You need to know how you can test for sugars, starch, proteins and lipids using different chemicals. You can carry out all of these tests on food samples.

Learning Objective:
- Be able to investigate the use of chemical reagents to identify reducing sugars, starch, proteins and fats. (Core Practical)

Specification Reference 1.13B

Preparing a food sample

For each of the tests on the next few pages, you need to prepare a food sample. If you're testing a solid food for reducing sugars, starch or proteins, you can prepare your sample for each test in the same way. Here's how the sample can be prepared:

1. Get a piece of your food and break it up using a pestle and mortar.
2. Transfer the ground up food to a beaker and add some distilled water.
3. Give the mixture a good stir with a glass rod.
4. Allow the mixture to settle out and then pipette out some of the liquid. This is your sample.

Preparing a food sample to test for lipids is slightly different — see page 45 for more.

Tip: If you're testing a liquid like milk or egg whites, you don't need to prepare your sample like this. You can just go straight ahead and test it.

Testing for reducing sugars

CORE PRACTICAL

Due to their chemical properties, sugars are classified as either reducing sugars (e.g. glucose) or non-reducing sugars (e.g. sucrose). You can test for reducing sugars in foods using the Benedict's test. Reducing sugars are found in things like biscuits and cereal, so these are good things to test. Here's what you'd do:

1. Transfer 5 cm^3 of a food sample to a test tube.
2. Prepare a water bath so that it's set to 75 °C.
3. Add some Benedict's reagent (which is blue) to the test tube (about 10 drops) using a pipette.
4. Place the test tube in the water bath using a test tube holder and leave it in there for 5 minutes. Make sure the tube is pointing away from you.
5. During this time, if the food sample contains a reducing sugar, a coloured precipitate (solid particles suspended in the solution) will form. The solution in the test tube will change from the normal blue colour to green, yellow or brick-red (see Figure 1). The higher the concentration of reducing sugar, the further the colour change goes — you can use this to compare the amount of reducing sugar in different solutions.

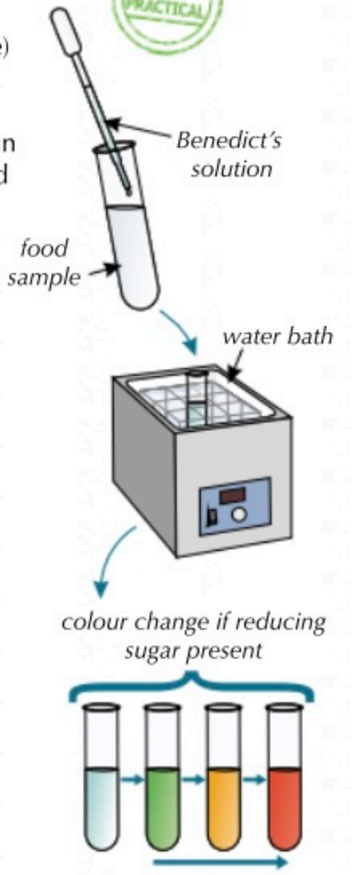

Benedict's solution
food sample
water bath
colour change if reducing sugar present
higher sugar concentration

Figure 1: *Steps involved in the Benedict's test.*

Tip: Make sure you're aware of the risks of the Benedict's test before you start. Wear eye protection and be very careful around the hot water in the water bath.

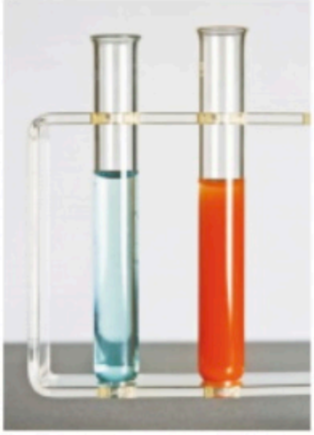


Figure 2: *A negative (left) and a positive (right) Benedict's test.*

Tip: A positive result is one where the test has identified the presence of what's being tested for (in this case a reducing sugar). A negative result is one where the test has not identified the presence of what's being tested for.

Testing for starch

CORE PRACTICAL

Tip: Make sure you assess and address the risks of the iodine test before you start. Wear eye protection, as iodine is an irritant to the eyes.

You can check for the presence of starch using the iodine test. Foods like pasta, rice and potatoes contain a lot of starch. Here's how to do the test:

1. Transfer 5 cm^3 of a food sample to a test tube.
2. Then add a few drops of iodine solution (iodine dissolved in potassium iodide solution) and gently shake the tube to mix the contents. If the sample contains starch, the colour of the solution will change from browny-orange to blue-black (see Figure 4).

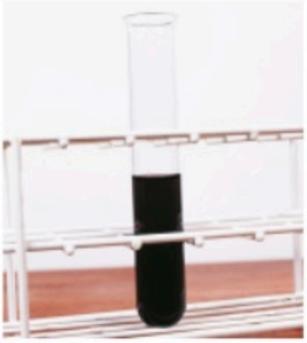


Figure 3: *A dark blue-black colour indicates the presence of starch in an iodine test.*

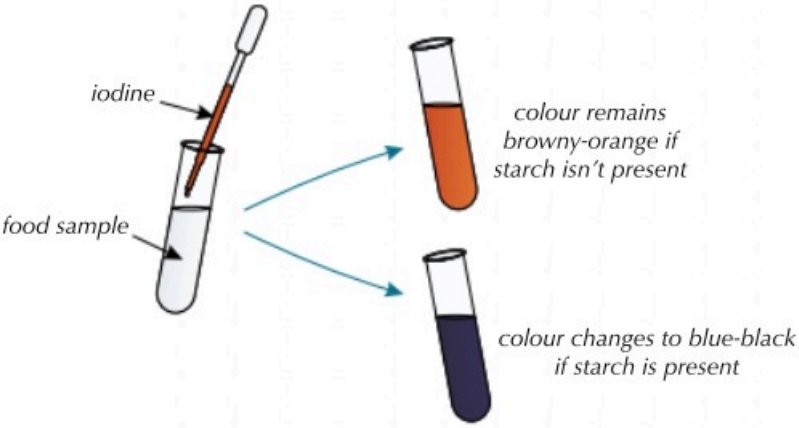

iodine
food sample
colour remains browny-orange if starch isn't present
colour changes to blue-black if starch is present

Figure 4: *The iodine test for starch.*

Testing for proteins

CORE PRACTICAL

Tip: Make sure you carry out a risk assessment before you perform the biuret test. The chemicals in the test are dangerous, so you'll need to wear safety goggles and make sure that you wash it off straight away if you get any on your skin.

You can use the biuret test to see if a sample contains protein. Meat and cheese are protein rich and good foods to use in this test. Here's how it's done:

1. Transfer 2 cm^3 of a food sample to a test tube.
2. Add 2 cm^3 of potassium hydroxide solution to make the solution alkaline.
3. Add a few drops of copper(II) sulfate solution (which is bright blue).
4. If the food sample contains protein, the solution will change from blue to pink or purple (see Figure 6). If no protein is present, the solution will stay blue.

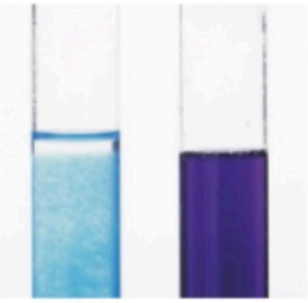


Figure 5: *Photo showing a negative (left) and positive (right) result for the biuret test for the presence of proteins.*

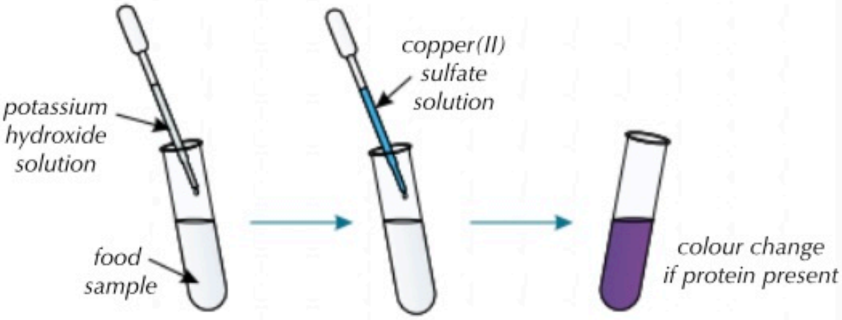

potassium hydroxide solution
food sample
copper(II) sulfate solution
colour change if protein present

Figure 6: *Steps involved in the biuret test.*

Testing for lipids (fats and oils)

CORE PRACTICAL

You can test for the presence of lipids using an emulsion test. Lipids are found in foods such as olive oil, margarine and milk. If you have a solid food sample, you'll first need to prepare it by grinding it up with a pestle and mortar (there's no need to add water).

1. Transfer some of the food sample into a test tube.
2. Add 2 cm^3 of ethanol to the test tube.
3. Shake the test tube well for about 1 minute until the test substance dissolves.
4. Pour the solution into a test tube containing 2 cm^3 of distilled water.
5. If there are any lipids present, they will precipitate out of the liquid and show up as a milky emulsion (see Figure 7). The more lipid there is, the more noticeable the milky colour will be.

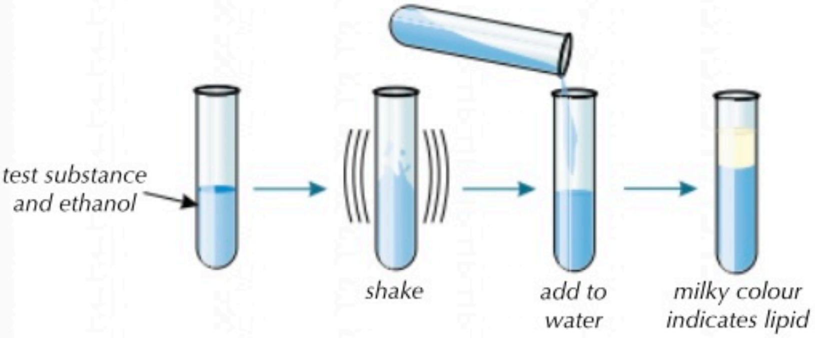


Figure 7: *Steps involved in the emulsion test.*

Practice Questions — Fact Recall

Q1 Describe the colour change that would occur during the iodine test if starch was present in the sample being tested.

Q2 A biuret test is carried out on a food sample that doesn't contain protein. What colour will the resulting solution be?

Practice Questions — Application

Q1 A student adds Benedict's reagent to a test tube containing a food sample. She leaves the test tube in a 75 °C water bath for 5 minutes. A yellow precipitate forms. Name the type of biological molecule that is present in the food sample.

Q2 A student has a food sample. Describe a test he could do to find out whether it contains lipids. In your description, you should include what the student should expect to see if the result is positive.

Tip: An emulsion is when one liquid doesn't dissolve in another — it just forms little droplets.

Tip: Make sure you do a risk assessment before you carry out the emulsion test. You must wear safety goggles. Ethanol is highly flammable, so keep it away from lit Bunsen burners.

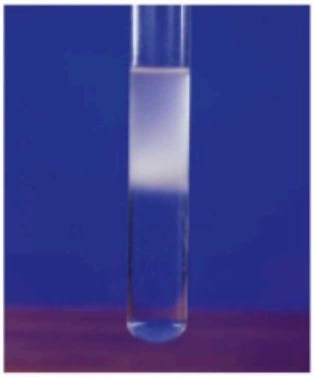


Figure 8: *A milky precipitate indicates the presence of lipid in an emulsion test.*

Tip: The tests described on pages 43-45 are all qualitative — you can tell whether or not a substance is present in a sample, but not how much is present. Even the Benedict's test is qualitative because you don't get a numerical value for the concentration of sugar (which would be a quantitative result). The results of these tests can all be recorded in a table, but can't be put into a graph.

5. Energy in Food

If you look at the nutrition labels on packets of food, you can see that all food contains energy. Calorimetry experiments can be used to work out how much energy different foods contain.

Learning Objective:

- Be able to explain how the energy contained in food can be measured using calorimetry.

Specification Reference 1.14B

Calorimetry

Food can be burnt to see how much energy it contains. The energy is released as heat. The posh name for this is calorimetry. You need to know how to do it with a simple experiment (see Figure 1).

1. Weigh a small amount of dry food and then skewer it on a mounted needle.
2. Add a set volume of water to a boiling tube (held with a clamp) — this will be used to measure the amount of energy that's transferred when the food is burnt.
3. Measure the temperature of the water with a thermometer, then set fire to the food using a Bunsen burner flame.
4. Immediately hold the burning food under the boiling tube until it goes out. Then relight the food and hold it under the tube — keep doing this until the food won't catch fire again.
5. Measure the temperature of the water again and record the temperature change.

Tip: Make sure you're aware of the risks of the calorimetry experiment before you begin. Wear eye protection and be very careful around any flames and hot equipment. Make sure you handle the mounted needle with care.

Tip: Dry foods, such as dried beans or pasta, will work best in calorimetry experiments.

Tip: Make sure the Bunsen burner isn't near the water or it may affect your results.

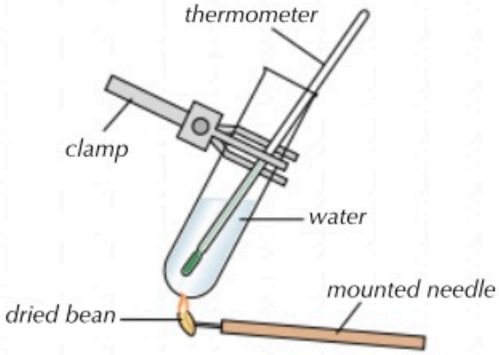


Figure 1: *A diagram to show the set-up of the calorimetry experiment.*

Calculating the amount of energy in food

You can use the results of this experiment to work out the amount of energy in the food per gram.

First, work out the total amount of energy in the food you burnt, using the formula below. The units for energy here are joules (J).

$$\text{energy in food (J)} = \text{mass of water (g)} \times \text{temperature change of water (°C)} \times 4.2$$

Tip: The 4.2 in the formula is the value of the specific heat capacity of water. It's the number of joules needed to raise the temperature of 1 g of water by 1 °C.

Tip: 1 cm^3 of water is the same as 1 g of water.

Now, work out how many joules are in each gram of the food. You need to do this, so you can compare the energy values of different foods fairly.

$$\text{energy per gram of food (J/g)} = \frac{\text{energy in food (J)}}{\text{mass of food (g)}}$$

Example

A student burned 0.2 g of popcorn and 0.5 g of bread separately under 20 cm^3 of water. During the experiment, the temperature of the water increased by 28.6 °C when the popcorn was burnt and 38.7 °C when the bread was burnt. Which food has more energy per unit mass?

1. First find the amount of energy in each type of food:

$$\text{Energy in food (J)} = \begin{matrix}\text{mass of}\\ \text{water (g)}\end{matrix} \times \begin{matrix}\text{temperature change}\\ \text{of water (°C)}\end{matrix} \times 4.2$$

$$\text{Energy in the popcorn} = 20\text{ g} \times 28.6\text{ °C} \times 4.2 = 2402.4\text{ J}$$

$$\text{Energy in the bread} = 20\text{ g} \times 38.7\text{ °C} \times 4.2 = 3250.8\text{ J}$$

2. Then convert this into joules per gram:

$$\text{Energy per gram of food (J/g)} = \frac{\text{energy in food (J)}}{\text{mass of food (g)}}$$

$$\text{Popcorn: } 2402.4 \div 0.2 = 12012.0\text{ J/g}$$

$$\text{Bread: } 3250.8 \div 0.5 = 6501.6\text{ J/g}$$

The popcorn has more energy per unit mass.

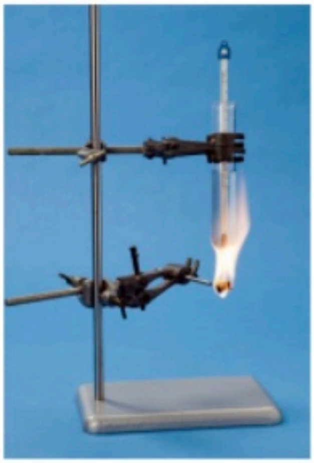


Figure 2: *The set-up of a calorimetry experiment to measure the amount of energy in a piece of food.*

These results are only an estimation of the amount of energy in the food being tested. If you look at the nutritional label on the food's packaging, the real energy content is likely to be higher.

That's because quite a bit of energy in the food is transferred to the environment rather than being used to raise the temperature of the water. Food scientists use fancy machines called calorimeters to measure the energy content of our food — they're insulated and sealed, so produce much more accurate results than any experiment that could be done in school.

Tip: You can minimise the amount of energy transferred to the environment by insulating the boiling tube, e.g. with foil.

Practice Question — Application

Q1 A student carries out an experiment to compare the energy content of a corn flake and a piece of pasta.

a) Describe an experiment that the student could carry out to help calculate the amount of energy contained in the corn flake.

b) Using the results of her experiment, the student calculates the total amount of energy in the corn flake and in the piece of pasta that she burnt. She compares the two values to see which piece of food contains more energy. Suggest why this might not be a fair comparison and what formula she could use to make the comparison of energy fair.

Learning Objective:

- Be able to explain how substances are transported into and out of cells, including by diffusion, osmosis and active transport.

Specification Reference 1.15

6. Transport in Cells

Substances can pass into and out of cells by diffusion, osmosis or active transport. The way substances move across cell membranes depends on the type of substance and its concentration across the membrane.

Diffusion

"Diffusion" is simple. It's just the gradual movement of particles from places where there are lots of them to places where there are fewer of them. That's all it is — just the natural tendency for stuff to spread out.

Here's fancy way of saying the same thing:

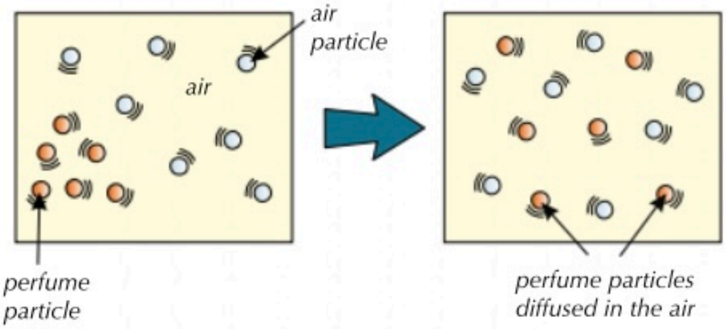
Diffusion is the spreading out of particles from an area of higher concentration to an area of lower concentration.

Tip: If something moves from an area of higher concentration to an area of lower concentration, it is said to have moved down a concentration gradient.

Diffusion happens in both solutions and gases — that's because the particles in these substances are free to move about randomly. The simplest type is when different gases diffuse through each other.

Example

When you spray perfume, the smell of perfume diffuses through the air in a room:



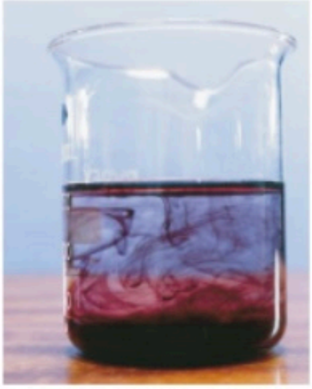


Figure 1: The ink particles in this flask are diffusing into the water — they're moving from an area of high concentration (at the bottom of the flask) to an area of low concentration (higher up).

Diffusion is a passive process — this means that it doesn't need energy to make it work.

Diffusion across cell membranes

Cell membranes are clever because they hold the cell together but they let stuff in and out as well. Dissolved substances can move in and out of cells by diffusion.

Cell membranes are **partially permeable**. This means they let some molecules through but not others. Only very small molecules can diffuse through cell membranes — things like oxygen (needed for respiration — see page 270), glucose, amino acids and water. Big molecules like starch and proteins can't fit through the membrane (see Figure 2 on the next page).

Tip: Partially permeable membranes have very small holes in them. Big molecules can't fit through the holes.

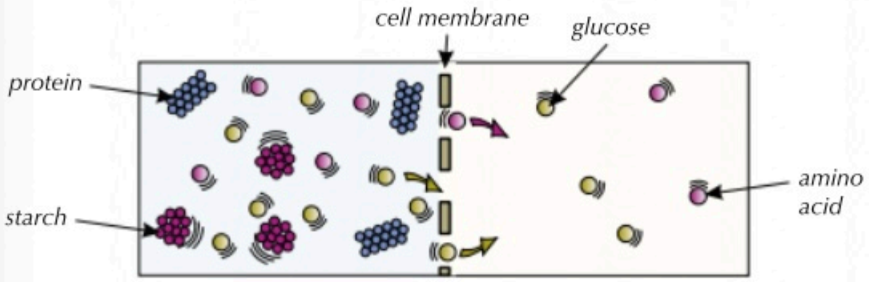


Figure 2: *Diagram to show diffusion across a cell membrane.*

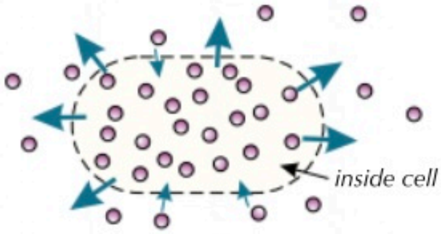
Just like with diffusion in air, particles flow through the cell membrane from where there's a higher concentration (more of them) to where there's a lower concentration (fewer of them).

They're only moving about randomly of course, so they go both ways — but if there are a lot more particles on one side of the membrane, there's a **net** (overall) movement from that side.

Exam Tip
If you're struggling to remember which way the particles move in diffusion, think of it like this: if you were in a really crowded place, you'd probably want to get out of there to somewhere with a bit more room. It's the same with particles — they always diffuse from an area of higher concentration to an area of lower concentration.

Example

Particles are diffusing both in and out of this cell. However, the concentration of particles is higher inside the cell than outside, so the net movement of particles is out of the cell.



Osmosis

Water molecules can move into and out of cells via a process called osmosis.

Osmosis is the net movement of water molecules across a partially permeable membrane from a region of higher water concentration to a region of lower water concentration.

You could also describe osmosis as the net movement of water molecules across a partially permeable membrane from a region of lower solute concentration to a region of higher solute concentration.

Tip: A solute is a molecule that's dissolved in water, e.g. sucrose.

The water molecules pass both ways through the membrane during osmosis. This happens because water molecules move about randomly all the time. But because there are more water molecules on one side than on the other, there's a steady net flow of water into the region with fewer water molecules, i.e. into the solution with the higher solute concentration. This means the more concentrated solution gets more dilute. The water acts like it's trying to "even up" the concentration either side of the membrane. This is shown in Figure 3 on the next page.

Tip: The sucrose solution has a higher concentration of solute (sucrose) than the pure water. So you can see that the net movement of water molecules is from the region of lower solute concentration to the region of higher solute concentration, as well as from the region of higher water concentration to the region of lower water concentration.

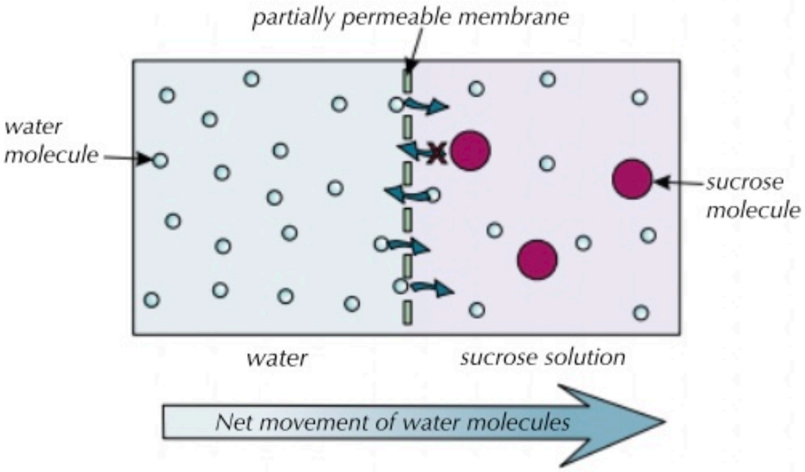

partially permeable membrane
water molecule
sucrose molecule
water
sucrose solution
Net movement of water molecules

Figure 3: *Diagram to show how osmosis works.*

Osmosis is a type of **diffusion** — passive movement of water particles from an area of higher water concentration to an area of lower water concentration.

The movement of water in and out of cells

Tip: Both plant and animal cells gain and lose water by osmosis.

The solution surrounding a cell will usually have a different concentration to the fluid inside the cell. This means that water will either move into the cell from the surrounding solution, or out of the cell, by osmosis.

If a cell is short of water, the solution inside it will become quite concentrated (i.e. there'll be a low concentration of water molecules). This usually means the solution outside the cell is more dilute (there's a higher concentration of water molecules), and so water will move into the cell by osmosis. If a cell has lots of water, the solution inside it will be more dilute, and water will be drawn out of the cell and into the fluid outside by osmosis.

This is summarised in Figure 4.

Tip: Cells that gain water by osmosis get a bit bigger (animal cells that gain too much water will eventually burst). Cells that lose water get a bit smaller.

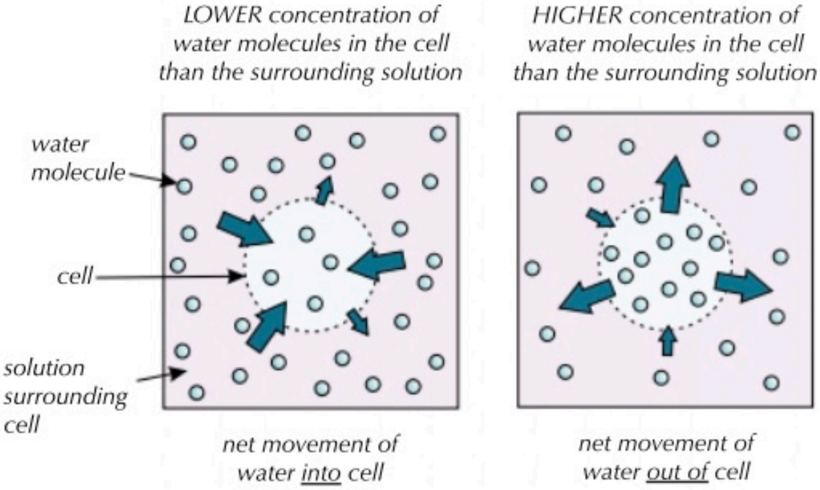

LOWER concentration of water molecules in the cell than the surrounding solution
HIGHER concentration of water molecules in the cell than the surrounding solution
water molecule
cell
solution surrounding cell
net movement of water *into* cell
net movement of water *out of* cell

Figure 4: *Diagram to show the movement of water molecules into and out of a cell.*

Active transport

Active transport is the movement of particles against a concentration gradient (i.e. from an area of lower concentration to an area of higher concentration) using energy transferred during respiration.

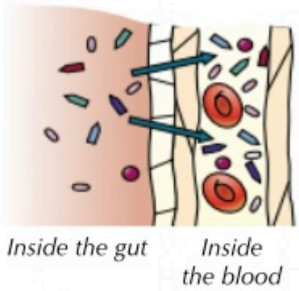
Active transport is a bit different from diffusion because particles are moved up a concentration gradient rather than down, and the process requires energy (unlike diffusion, see page 48). It allows cells to absorb substances from very dilute solutions. Here's an example of active transport at work in the digestive system:

Exam Tip
You could be asked in the exam to compare diffusion, osmosis and active transport. Make sure you know the similarities and differences between them all.

Example

When there's a higher concentration of nutrients in the gut than in the blood, the nutrients diffuse naturally into the blood. BUT — sometimes there's a lower concentration of nutrients in the gut than in the blood.

Active transport allows nutrients to be taken into the blood, despite the fact that the concentration gradient is the wrong way. This is essential to stop us starving. It means that glucose can be taken into the bloodstream when its concentration in the blood is already higher than in the gut. The glucose can then be transported to cells, where it's used for respiration (see pages 270-272).



Tip: Active transport is also useful in plants, e.g. to absorb mineral ions from the soil. See page 209 for more.

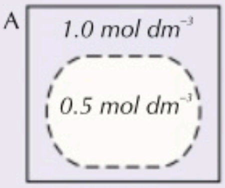
Practice Questions — Fact Recall

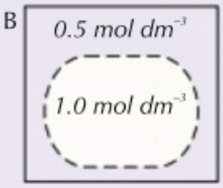
Q1 What is osmosis?

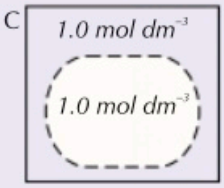
Q2 Explain how cells can absorb ions from very dilute solutions.

Practice Question — Application

Q1 The diagrams below show three cells in different glucose solutions. The concentration of glucose inside and outside the cell is shown in each case. Which diagram shows a situation where the net movement of glucose will be out of the cell — A, B or C?







7. Investigating Osmosis in Plant Cells

Learning Objectives:
- Be able to investigate osmosis in potatoes. (Core Practical)
- Be able to calculate percentage gain and loss of mass in osmosis.

Specification References
1.16, 1.17

Plant cells gain and lose water by osmosis. You can investigate how changing the concentration of the solution surrounding the cell affects osmosis.

Investigating the effect of sugar solutions on plant cells

CORE PRACTICAL

Tip: As with all experiments, make sure you carry out a risk assessment before you start this practical.

Here's an experiment you can do to show osmosis at work:

1. Prepare sucrose solutions of different concentrations ranging from pure water to a very concentrated sucrose solution.
2. Use a cork borer to cut a potato into the same sized pieces (the pieces need to be about 1 cm in diameter and preferably from the same potato).
3. Divide the cylinders into groups of three and use a mass balance to measure the mass of each group.
4. Place one group in each solution.
5. Leave the cylinders in the solution, as shown in Figure 1, for at least 40 minutes (making sure that they all get the same amount of time).

Tip: Make sure there's no skin left on your potato cylinders, as this could affect your results.

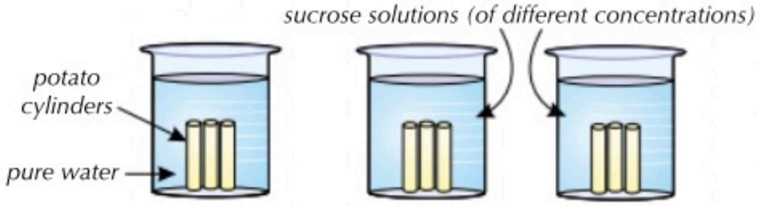


Figure 1: *A diagram to show the set-up of the experiment.*

Tip: You could also carry out this experiment using different salt solutions or by investigating the effect on cylinder length instead of mass.

5. Remove the cylinders and pat dry gently with a paper towel. This removes excess water from the surface of the cylinders, so you get a more accurate measurement of their final masses.
6. Weigh each group again and record your results.

Variables and errors

WORKING SCIENTIFICALLY

The **dependent variable** in this experiment is the cylinder mass and the **independent variable** is the concentration of the sucrose solution. All other variables (volume of solution, the size of potato cylinders, the age and type of potatoes used, the amount of drying, etc.) must be kept the same in each case. Otherwise, the experiment won't be a fair test and your results won't be valid.

Tip: There's more on variables on page 10.

Like any experiment, you need to be aware of how errors (see p.13) may arise. Sometimes they may occur when carrying out the method, e.g. if some potato cylinders were not fully dried, the excess water would give a higher mass, or if water evaporated from the beakers, the concentrations of the sugar solutions would change. You can reduce the effect of these errors by repeating the experiment and calculating a mean percentage change at each concentration.

Tip: You can read all about how to calculate a mean on page 14.

Interpreting the results

Once you have got all your results, you need to calculate the percentage change in mass for each group of cylinders before and after their time in the sucrose.

$$\text{percentage change in mass} = \frac{\text{final mass} - \text{initial mass}}{\text{initial mass}} \times 100$$

Tip: By calculating the percentage change, you can compare the effect of sucrose concentration on cylinders that didn't have the same initial mass. An increase in mass will give a positive percentage change and a decrease will give a negative percentage change.

Example

A group of cylinders weighed 13.2 g at the start of the experiment. At the end they weighed 15.1 g. Calculate the percentage change in mass.

The percentage change in mass is: $\frac{\text{final mass} - \text{initial mass}}{\text{initial mass}} \times 100$

$$= \frac{15.1 - 13.2}{13.2} \times 100 = \mathbf{14.4\%}$$

Tip: Make sure your initial mass and final mass have the same units.

Producing a graph of your results

You can create a graph of your results by plotting the percentage change in mass against the concentration of sucrose solution. You can then draw a line of best fit, which you can use to determine the concentration of the solution in the potato cells:

Tip: There's more about plotting graphs on pages 16-18.

Example

An experiment to investigate the effect of sucrose concentration on potato cells gave the results in the table below.

Concentration of sucrose solution (M)	*0.1*	*0.25*	*0.5*	*1.0*	*2.0*
Percentage change in mass (%)	*16.5*	*2.5*	*–8.0*	*–15.5*	*–20.0*

The results are plotted as a graph, with concentration of sucrose solution on the *x*-axis and percentage change in mass on the *y*-axis (see Figure 2).

- At the points above the *x*-axis, the concentration of water molecules in the sucrose solutions is higher than in the cylinders. The cylinders gain mass as water is drawn in by osmosis.
- At the points below the *x*-axis, the concentration of water molecules in the sucrose solutions is lower than in the cylinders. This causes the cylinders to lose water, so their mass decreases.

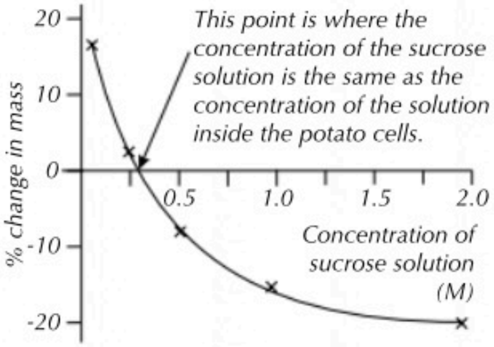


Figure 2: *A graph to find the concentration of the solution inside the potato cells.*

Tip: 'M' is a unit of concentration. You might also see it written as mol dm^{-3}. A solution with a concentration of 0.00 M would be pure water, so the 0.1 M sucrose solution has a much higher concentration of water molecules than the 2.0 M solution.

Tip: When the fluid inside the cylinders is the same concentration as the sucrose solution, the two fluids are said to be isotonic.

- The point at which the line of best fit crosses the *x*-axis (where the percentage change in mass is 0) is the point at which the concentration of the sucrose solution is the same as the concentration of the solution in the potato cells. You can estimate the concentration of the solution inside the potato cells by reading the value off the *x*-axis at this point.

Exam Tip
You could get asked questions about any of the Core Practicals in the exam — so make sure you understand what's happening in each one.

Practice Question — Application

Q1 An experiment is carried out to investigate osmosis.

A potato is cut up into cylinders of the same known length and width. Two different concentrations of sucrose solution are prepared in two separate beakers. Three potato cylinders are then placed into each beaker.

The potato cylinders are left for several hours and then the length of each cylinder is measured again. The final mean cylinder length is recorded for each beaker.

a) What is:

i) the dependent variable in this experiment?

ii) the independent variable in this experiment?

b) Give two variables that need to be controlled in this experiment so that the experiment is a fair test.

c) The potato cylinders in one beaker were 9.6 cm long at the start of the experiment. At the end of the experiment, they had a mean length of 8.5 cm. Calculate the percentage change in mean length.

Topic 1b Checklist — Make sure you know...

Enzymes

☐ That enzymes are biological catalysts, speeding up the rate of chemical reactions in living things.

☐ That every enzyme has its own unique active site, and it's the shape of this active site that allows the enzyme to bind to its substrate.

☐ That enzymes will usually only bind to one specific substrate, so if the substrate doesn't fit the active site, the reaction won't be catalysed. This is the 'lock and key' model of enzyme action.

☐ That increasing the temperature increases the rate of an enzyme-controlled reaction until it gets so hot that some of the bonds holding the enzyme together break. The active site then changes shape and no longer fits the substrate — the enzyme is denatured.

☐ That increasing the substrate concentration increases the rate of an enzyme-controlled reaction until there are enough substrate molecules to occupy all available enzyme active sites (after which it has no effect).

☐ That extreme pH levels decrease the rate of an enzyme-controlled reaction by interfering with bonds in the active site, changing the shape of the active site and denaturing the enzyme.

cont...

Investigating Enzymatic Reactions

☐ How to investigate the effects of pH on enzyme activity, for example, on the rate of the breakdown of starch by the enzyme amylase (Core Practical).

☐ How to calculate the rate of an enzyme controlled reaction.

Enzymes in Breakdown and Synthesis

☐ That enzymes catalyse the breakdown of large biological molecules into smaller biological molecules so that they can be used for growth and other life processes.

☐ That carbohydrases convert carbohydrates into simple sugars.

☐ That proteases catalyse the conversion of proteins into amino acids.

☐ That lipases catalyse the conversion of lipids (fats and oils) into glycerol and fatty acids.

☐ That enzymes catalyse the synthesis of carbohydrates, proteins and lipids from smaller molecules.

Testing for Biological Molecules

☐ How to test for the presence of reducing sugars, starch, proteins and lipids using the Benedict's test, iodine test, biuret test and emulsion test (Core Practical).

Energy in Food

☐ How to measure the amount of energy in different foods using calorimetry.

Transport in Cells

☐ That diffusion is the spreading out of particles from an area of higher concentration to an area of lower concentration.

☐ That dissolved substances such as glucose, oxygen and amino acids move in and out of a cell by diffusion, and that the net (overall) movement will be to an area of lower concentration.

☐ That osmosis is the movement of water molecules across a partially permeable membrane from a region of higher water concentration (a dilute solution) to a region of lower water concentration (a more concentrated solution).

☐ How differences in the concentration of water molecules inside and outside of a cell will cause water molecules to move into or out of the cell by osmosis.

☐ That active transport is the movement of particles against a concentration gradient (i.e. from an area of lower concentration to an area of higher concentration) using energy transferred by respiration.

Investigating Osmosis in Plant Cells

☐ How to investigate the effect of different concentrations of a sugar or salt solution on osmosis in potato cells (Core Practical).

☐ How to calculate percentage change in mass for plant tissue (e.g. a piece of potato).

Exam-style Questions

1 Scientists can use a range of simple tests to detect the presence of certain substances in different types of food. A scientist was testing a food sample for the presence of glucose, a reducing sugar.

(a) What reagent should she use?

(1 mark)

(b) The result of the test was no colour change.
What does this suggest about the presence of glucose in the sample?

(1 mark)

(c) Following the test for reducing sugars, the scientist decided to test a fresh sample of the food for starch. Name the reagent that she would have used and describe what she would have seen if the result was positive.

(3 marks)

2 A student was measuring the rate that carbon dioxide (CO_2) was produced in a reaction controlled by enzyme X. He performed the experiment at three different temperatures — 10 °C, 25 °C and 50 °C. The experiment at 50 °C produced no carbon dioxide at all.

His results are shown in **Figure 1**.

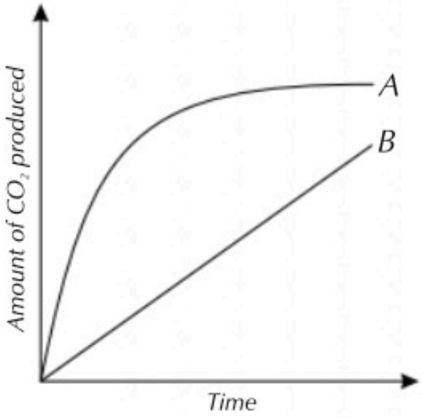


Figure 1

(a) Enzyme X is only able to catalyse this reaction.
Explain why most enzymes can only catalyse a single reaction.

(2 marks)

(b) Suggest which line on **Figure 1** (**A** or **B**) represents the experiment carried out at 25 °C. Explain your answer.

(2 marks)

(c) Suggest why the experiment at 50 °C failed to produce any CO_2.

(2 marks)

3 The conditions inside the stomach are acidic due to the presence of hydrochloric acid (HCl acid). An experiment was done to show how digestion in the stomach works. The enzyme pepsin is a protease found in the stomach. In the experiment, three equally sized pieces of meat were added to each of three test tubes. Then the test tubes were filled with equal volumes of the following substances:

Test tube 1: hydrochloric acid
Test tube 2: pepsin
Test tube 3: pepsin and hydrochloric acid

The results are shown in **Figure 2**.

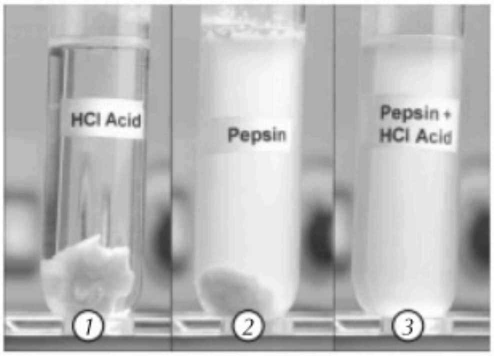

HCl Acid
Pepsin
Pepsin + HCl Acid
①
②
③

Figure 2

Describe the results and explain what they suggest about pepsin.

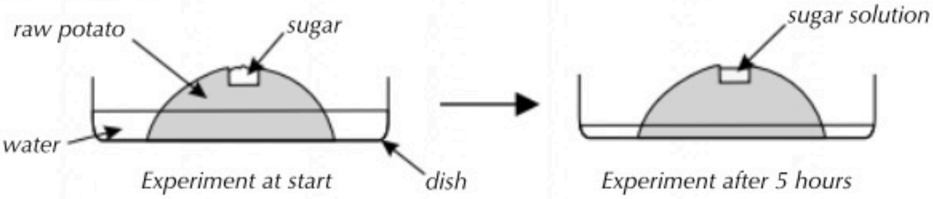
(3 marks)

4 Eleanor is investigating osmosis using potatoes.

She cuts small wells into two pieces of potato, and sets up two experiments (A and B). She then leaves the potatoes for five hours.

Figure 3 shows how the appearance of each experiment changes after five hours.

Experiment A


raw potato
sugar
sugar solution
water
dish
Experiment at start
Experiment after 5 hours

Experiment B

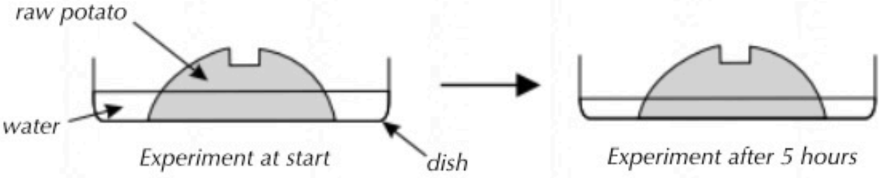

raw potato
water
dish
Experiment at start
Experiment after 5 hours

Figure 3

(a) Explain the changes that Eleanor saw in experiment A.

(3 marks)

(b) Suggest an explanation for why the water level in the dish in experiment B didn't decrease as much as much as that in experiment A.

(3 marks)

1. Mitosis

Our body cells are able to make copies of themselves so that we can grow or repair any damaged tissue. It's pretty clever stuff...

Learning Objectives:

- Be able to describe mitosis as part of the cell cycle, including the stages interphase, prophase, metaphase, anaphase and telophase and cytokinesis.
- Be able to describe the division of a cell by mitosis as the production of two daughter cells, each with identical sets of chromosomes in the nucleus to the parent cell, and that this results in the formation of two genetically identical diploid body cells.
- Be able to describe the importance of mitosis in growth, repair and asexual reproduction.

Specification References 2.1 – 2.3

Tip: See pages 89-91 for more on DNA.

Figure 2: *A pair of human chromosomes seen under a microscope.*

Body cells and chromosomes

Most cells in your body have a structure called a **nucleus** (see page 23). The nucleus contains your genetic material (the instructions you need to grow and develop). This material is stored in the form of **chromosomes** — see Figure 1.

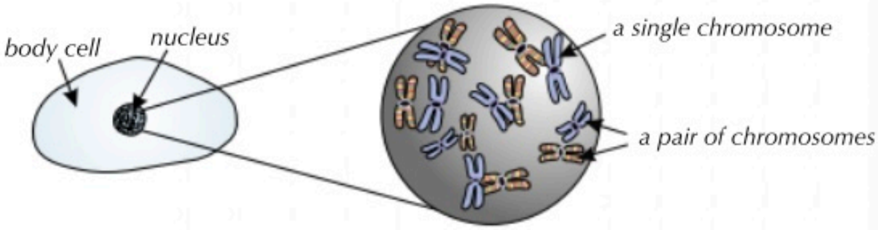


Figure 1: *Diagram to show that a cell nucleus contains chromosomes.*

Body cells normally have two copies of each chromosome — this makes them '**diploid**' cells. One chromosome comes from the organism's 'mother', and one from its 'father'.

Chromosomes and DNA

Chromosomes are long lengths of a molecule called **DNA**.
The DNA is coiled up to form the arms of the chromosome (see Figure 3).

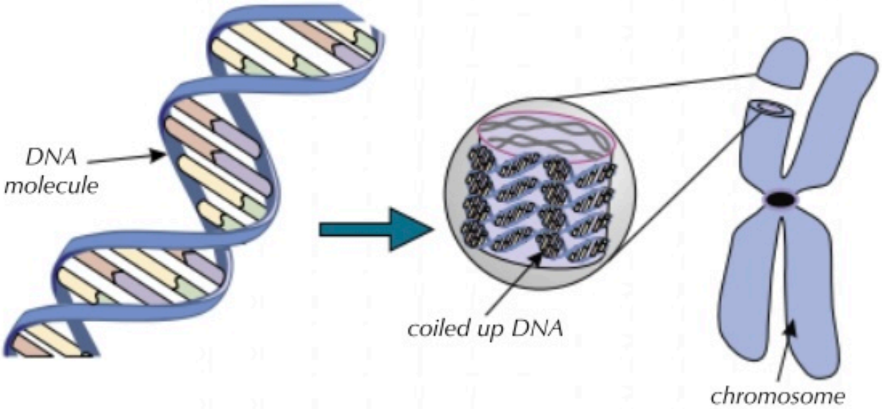


Figure 3: *Diagram to show how DNA coils up to form a chromosome.*

Mitosis and the cell cycle

Body cells in multicellular organisms divide to produce new cells during a process called the cell cycle. The cell cycle starts when a cell has been produced by cell division and ends with the cell dividing to produce two identical cells. It can be summarised as a stage of cell growth and DNA replication (called **interphase**, see below), followed by a stage of cell division (see Figure 4).

The stage of the cell cycle when the cell divides is called **mitosis**:

> Mitosis is when a cell reproduces itself by splitting in two to form two genetically identical offspring.

Mitosis can also specifically refer to the division of the nucleus rather than the whole cell. **Cytokinesis** (the division of the cytoplasm) takes place at the same time. The end of the cell cycle results in two new genetically identical diploid cells.

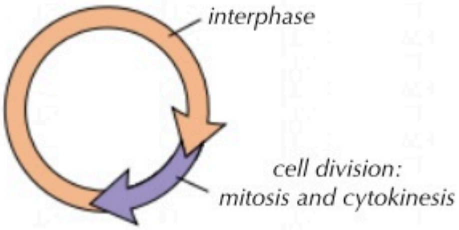


Figure 4: *Diagram outlining the cell cycle.*

As a cell goes through the cell cycle, it has to undergo some key changes.

What happens during the cell cycle?

Here are the steps involved in the cell cycle:

Interphase

1. In a cell that's not dividing, the DNA is all spread out in long strings (see Figure 5).
2. Before it divides, the cell has to grow and increase the amount of subcellular structures such as mitochondria and ribosomes.

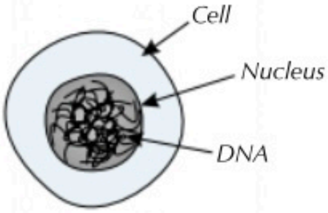
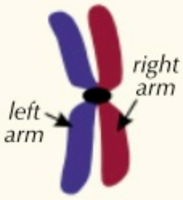


Figure 5: *Diagram of a cell in interphase.*

3. It then duplicates its DNA — so there's one copy of each chromosome for each new cell. The DNA is copied and forms X-shaped chromosomes. Each 'arm' of the chromosome is an exact duplicate of the other. Each 'arm' is called a chromatid.

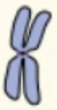
Now the cell is ready for mitosis...

Tip: When a cell has copied its DNA, the left arm of an X-shaped chromosome has the same DNA as the right arm.

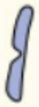


Exam Tip
You need to remember all these stages, and in the correct order too. A memory aid like this one might help you: In Plymouth My Aunt Teaches Chemistry (interphase, prophase metaphase, anaphase, telophase, cytokinesis).

Tip: Chromosomes only look like this:



just before the cell divides (see previous page). After the nucleus has divided, the chromosomes in each set look like this:



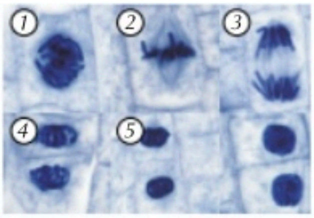


Figure 7: *A series of photos showing an onion cell in mitosis. 1 = prophase, 2 = metaphase, 3 = anaphase, 4&5 = telophase.*

Exam Tip
In the exam, you might have to identify or describe what's going on in photos of real cells undergoing mitosis, so make sure you learn what the different stages look like.

Mitosis

Mitosis is really one continuous process, but it can be divided into four stages:

1. **Prophase**
   The chromosomes condense, getting shorter and fatter. The membrane around the nucleus breaks down and the chromosomes lie free in the cytoplasm.
2. **Metaphase**
   The chromosomes line up at the centre of the cell.
3. **Anaphase**
   Spindle fibres pull the chromosomes apart. The two arms of each chromosome (chromatids) are pulled to opposite ends of the cell.
4. **Telophase**
   Membranes form around each of the sets of chromosomes. These become the nuclei of the two new cells — the nucleus has divided.

Cytokinesis

Before telophase ends, the cytoplasm and cell membrane divide to form two separate cells — this process is called **cytokinesis**.

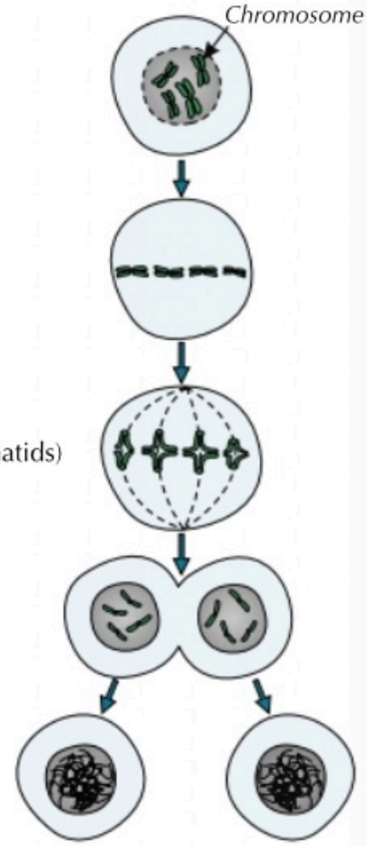


Figure 6: *Diagram showing mitosis and cytokinesis in the cell cycle.*

At the end of mitosis, the cell has produced two new daughter cells. Each daughter cell contains exactly the same set of chromosomes in its nucleus — the two cells are genetically identical. They're also genetically identical to the diploid parent cell. This makes the daughter cells diploid too.

Uses of mitosis

Mitosis is used:

- By multicellular organisms to grow.
- By multicellular organisms to replace cells that have been damaged.
- By some organisms to reproduce by **asexual reproduction**:

Example

Figure 8: *Strawberry plant with runner (red stem).*

Strawberry plants form runners by mitosis (see Figure 8). These runners take root and new plants grow from them (also by mitosis). These new plants (the offspring) have exactly the same DNA as the parent.

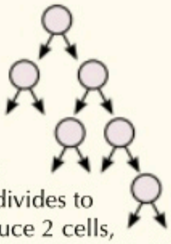
Calculating the number of cells

You can calculate the number of cells there will be after multiple divisions of a cell by mitosis. The formula you need is:

$$\text{number of cells} = 2^n$$

'*n*' is the number of divisions by mitosis.

Tip:



Each cell divides to produce 2 cells, so the number of cells increases by a power of 2 for each division.

Example

MATHS SKILLS

A population of cells is dividing continually by mitosis. The population started with one cell. How many cells were in the population after five divisions of mitosis?

- Stick the value for 'n' into the equation, number of cells = 2^n:

  $$\text{number of cells} = 2^5$$

- Calculate the answer:

  $$\text{number of cells} = \mathbf{32}$$

Tip: 2^5 is the same as $2 \times 2 \times 2 \times 2 \times 2$.

Practice Questions — Fact Recall

Q1 Describe what happens to the DNA in a cell during interphase.

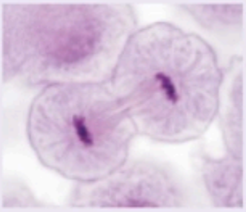
Q2 Describe what happens during anaphase of mitosis.

Q3 Name the process by which a cell's cytoplasm and cell membrane divide to form two new cells.

Q4 Give two uses of mitosis in multicellular organisms.

Practice Questions — Application

Q1 This photograph shows the last stage in mitosis — two new daughter cells are formed.



a) Will these new cells be genetically identical or genetically different to the parent cell?

b) How many sets of chromosomes will these cells have?

c) Describe what is happening in the photograph.

Q2 A scientist is studying mitosis in yeast cells. A sample contains one yeast cell, which begins dividing. How many cells will there be in the sample after ten divisions?

Exam Tip
You don't have to know anything to do with the specific cells to answer a mitosis question like this in the exam.

Learning Objectives:

- Be able to explain the importance of cell differentiation in the development of specialised cells.
- Be able to describe growth in organisms, including cell division and differentiation in animals.
- Be able to describe growth in organisms, including cell division, elongation and differentiation in plants.
- Be able to describe cancer as the result of changes in cells that lead to uncontrolled cell division.
- Be able to demonstrate an understanding of the use of percentiles charts to monitor growth.

Specification References
2.4 – 2.7

2. Cell Division and Growth

All organisms grow. You need to know the processes involved in both animal and plant growth, as well as how percentile charts are used to monitor growth.

Growth and development

Growth is an increase in size or mass. Plants and animals grow and develop due to these processes:

- **Cell division**
  This happens by mitosis (see pages 59-60).
- **Cell differentiation**
  Cell differentiation is the process by which a cell changes to become specialised for its job. Having specialised cells (see page 26) allows multicellular organisms to work more efficiently because different cell types can carry out different functions.

Plants also grow by **cell elongation**. This is where a plant cell expands, making the cell bigger and so making the plant grow.

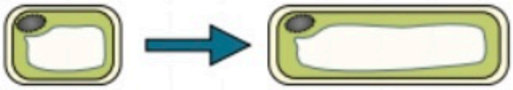


Figure 1: *A plant cell elongating.*

Growth in animals

All growth in animals happens by cell division. Animals tend to grow while they're young, and then they reach full growth and stop growing. So when you're young, cells divide at a fast rate but once you're an adult, most cell division is for repair — the cells divide to replace old or damaged cells. This also means that, in most animals, cell differentiation is lost at an early stage.

Tip: Cell elongation is also used to control the direction of a plant's growth — see pages 215-217.

Growth in plants

In plants, growth in height is mainly due to cell elongation. Cell division usually just happens in the tips of the roots and shoots (in areas called **meristems** — see pages 65-66). But plants often grow continuously — even really old trees will keep putting out new branches. So, plants continue to differentiate to develop new parts, e.g. leaves, roots.

Cancer

The body controls the amount of cell division that happens for growth, so cells will normally stop dividing when enough new cells have been produced. The rate at which cells divide by mitosis is controlled by the chemical instructions (genes) in an organism's DNA.

If there's a change in one of the genes that controls cell division, the cell may start dividing uncontrollably — growth doesn't stop. This can result in a mass of abnormal cells called a **tumour**. If the tumour invades and destroys surrounding tissue it is called cancer.

Tip: A random change in a gene is called a mutation — see pages 93-94.

Percentile charts

Percentile charts can be used to assess a child's growth over time, so that an overall pattern in development can be seen and any problems highlighted (e.g. obesity, malnutrition, dwarfism).

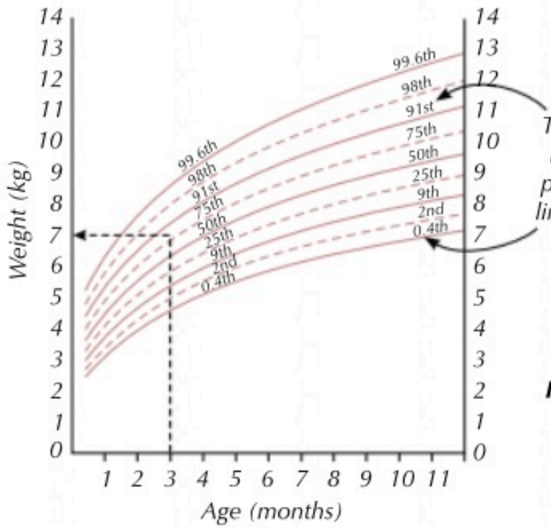
For example, a baby's growth is regularly monitored after birth to make sure it's growing normally. Three measurements are taken — length, mass and head circumference. These results are plotted on percentile growth charts like the one in the example below.

These charts show a number of 'percentiles'. Each percentile represents one percent of the data, so if you were looking at a percentile chart for mass, the 50th percentile would show the mass that 50% of babies will have reached at a certain age.

Tip: Head circumference is the measurement of the distance around the largest area of the head. It's measured to check for things like problems with the development of the brain.

Example

The growth chart in Figure 2 shows that a three-month-old boy who weighs 7 kg is just above 75th percentile for weight — roughly 75% of three-month-old boys are lighter and 25% are heavier.



These numbers indicate what percentile each line on the chart represents.

Figure 2: *Growth chart for boys, aged 0-1 years.*

Tip: Percentiles tell you where in the data set a data point lies. The value of a percentile tells you what percentage of data has a value equal to or lower than the data points in that percentile.

Tip: The median is the middle value in a data set (see page 14) so the 50th percentile is the median.

Babies vary in size, but doctors are likely to investigate if a baby's size is above the top percentile line or below the bottom percentile line, their size increases or decreases by two or more percentile lines over time, or if there's an inconsistent pattern (e.g. a small baby with a very large head).

Practice Questions — Fact Recall

Q1 What is cell differentiation?

Q2 Describe how changes in a cell can result in cancer.

Practice Question — Application

Q1 A baby is in the 60th percentile for weight. What percentage of babies of the same age weigh either the same or less than this baby?

3. Stem Cells

All the cells in an organism originate from stem cells. Scientists are attempting to use these cells to do some pretty amazing things...

Learning Objectives:

- Be able to describe the function of embryonic stem cells and stem cells in animals.
- Be able to discuss the potential benefits and risks associated with the use of stem cells in medicine.
- Be able to describe the function of meristems in plants.

Specification References 2.8, 2.9

Tip: Ciliated epithelial cells are specialised cells. There's more about them on page 27.

What are stem cells?

Some cells are undifferentiated (i.e. they have not yet changed to become specialised for a particular job). These undifferentiated cells are called **stem cells**. They can divide to produce lots more undifferentiated cells. These new cells can then develop into different types of cell, depending on what instructions they're given.

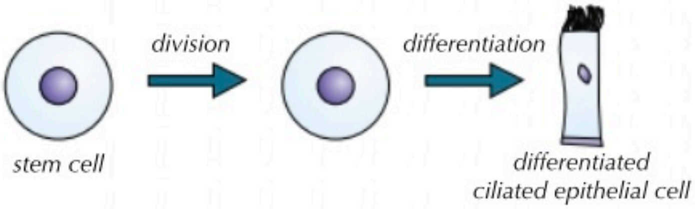


Figure 1: *Diagram showing a differentiated cell resulting from a stem cell.*

Stem cells are found in early human embryos. These embryonic stem cells have the potential to divide and produce any kind of cell at all. This makes sense if you think about it — all the different types of cell found in a human being have to come from those few cells in the early embryo. This means embryonic stem cells are really important for the growth and development of organisms.

Adults also have stem cells, but they're only found in certain places, like bone marrow (the spongy tissue inside bones). These aren't as versatile as embryonic stem cells — they can't produce any cell type at all, only certain ones. In animals, adult stem cells are used to replace damaged cells, e.g. to make new skin or blood cells.

Adult stem cells in medicine

Adult stem cells are already used to cure disease.

Example

People with some blood diseases (e.g. sickle cell anaemia, a disease which affects the red blood cells) can be treated by bone marrow transplants. Bone marrow contains adult stem cells that can turn into new blood cells to replace the faulty old ones.

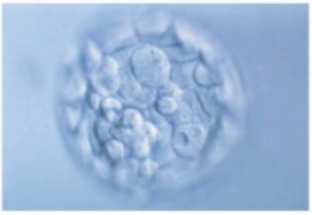


Figure 2: *Microscope image of a human embryo that's about 4 days old. Stem cells can be taken from the embryo at this stage.*

Embryonic stem cells in medicine

Scientists have experimented with extracting stem cells from very early human embryos and growing them. Under certain conditions, the stem cells can be stimulated to differentiate into specialised cells. In the future, it might be possible to use embryonic stem cells to replace faulty cells in sick people (see Figure 3 on the next page).

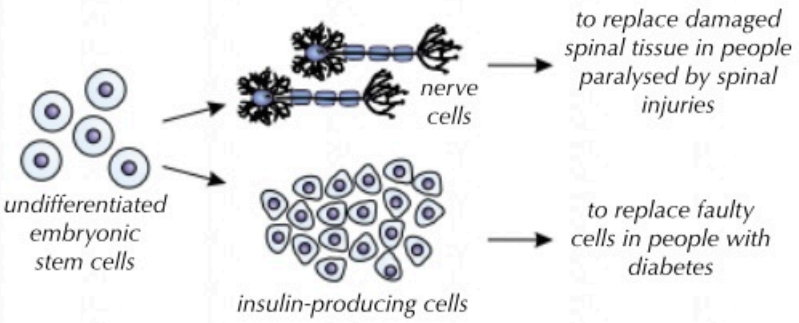

to replace damaged spinal tissue in people paralysed by spinal injuries
nerve cells
undifferentiated embryonic stem cells
to replace faulty cells in people with diabetes
insulin-producing cells

Figure 3: *Diagram showing some potential uses of embryonic stem cells in medicine.*

Tip: The advantage of using embryonic stem cells for therapies over adult stem cells is that they have the potential to differentiate into many different types of cell (unlike adult stem cells, which are limited to differentiating into certain types of cell). They are also easier to grow in culture than adult stem cells.

Issues involved in using stem cells

WORKING SCIENTIFICALLY

Before specialised cells created from stem cells can be used for medical treatments, a lot of research needs to be done. There are many potential risks which scientists need to learn more about.

Examples

- Tumour development — stem cells divide very quickly. If scientists are unable to control the rate at which the transplanted cells divide inside a patient, a tumour may develop (see page 62).
- Disease transmission — viruses live inside cells. If donor stem cells are infected with a virus and this isn't picked up, the virus could be passed on to the recipient and so make them sicker.
- Rejection — if the transplanted cells aren't grown using the patient's own stem cells, the patient's body may recognise the cells as foreign and trigger an immune response to try to get rid of them. The patient can take drugs to suppress this response, but this makes them susceptible to diseases.

Exam Tip
Questions on the issues associated with using stem cells in medicine might crop up in the exam, so make sure you know the potential benefits and the risks associated with using them.

Ethical issues

Research using embryonic stem cells also raises ethical issues.

Some people are against it, because they feel that human embryos shouldn't be used for experiments since each one is a potential human life.

However, others think that curing patients who already exist and who are suffering is more important than the rights of embryos. One fairly convincing argument in favour of this point of view is that the embryos used in the research are usually unwanted ones from fertility clinics which, if they weren't used for research, would probably just be destroyed. However, many campaigners for the rights of embryos think this should be banned too.

Tip: Obtaining stem cells from an embryo destroys the embryo.

Tip: In some countries stem cell research is banned, but it's allowed in the UK as long as it follows strict guidelines.

Stem cells in plants

In plants, the only cells that divide by mitosis are found in plant tissues called **meristems**. Meristem tissue is found in the areas of a plant that are growing, e.g. the tips of the roots and shoots.

Figure 4: *Plants grown from meristem tissue.*

Meristems produce unspecialised cells that are able to divide and form any cell type in the plant — they act like embryonic stem cells. But unlike human stem cells, these cells can divide and differentiate to generate any type of cell for as long as the plant lives.

The unspecialised cells go on to form specialised tissues like xylem and phloem (see page 207).

Practice Questions — Fact Recall

Q1 What is a stem cell?

Q2 In terms of their ability to produce different cell types, what is the difference between early embryonic stem cells and adult stem cells?

Q3 Give two potential risks of using stem cells in medical treatments.

Q4 Name the tissue in plants where stem cells can be found.

Practice Questions — Application

Q1 Adult stem cells can only be found in certain places in the body. One place is the skin. Suggest why adult stem cells are needed in the skin.

Q2 Alzheimer's disease is a condition which damages the neurones (nerve cells) in the brain. These neurones die, but are not replaced, leading to a decrease in the amount of neurones in the brain. Symptoms of Alzheimer's disease include memory loss, confusion and changes in personality.

a) Suggest a way in which embryonic stem cells could potentially be used to treat people with Alzheimer's disease.

b) Suggest another possible use of embryonic stem cells in medicine.

Q3 Embryonic stem cells used for medical research are mostly taken from embryos left over from fertility clinics, which would otherwise be destroyed. Suggest a reason why some people are happier with using these embryos for stem cell research, rather than creating embryos purely with the purpose of being used for research.

Topic 2a Checklist — Make sure you know...

Mitosis

☐ That body cells divide by mitosis, as part of the cell cycle.

☐ That the cell cycle also includes interphase, during which a cell grows, increases the amount of its subcellular structures and makes a copy of its DNA.

☐ That the stages of mitosis are prophase, metaphase, anaphase and telophase. During prophase, the chromosomes condense and the membrane around the nucleus breaks down. In metaphase, the chromosomes line up at the centre of the cell. In anaphase, spindle fibres pull the chromosomes apart. Then in telophase, membranes form around each of the sets of chromosomes to create the nuclei of the two new cells.

☐ That cytokinesis (the division of the cytoplasm and cell membrane to create two separate cells) takes place before telophase ends.

☐ That mitosis produces two new genetically identical diploid cells (with two sets of chromosomes each).

☐ That mitosis allows organisms to grow and replace damaged cells.

☐ That mitosis is used by some organisms to reproduce asexually.

Cell Division and Growth

☐ That growth in animals and plants can involve cell division and differentiation.

☐ That cell differentiation (where a cell changes to become specialised for its job) is important for allowing multicellular organisms to work efficiently.

☐ That growth in plants can also involve cell elongation (where the plant cells expand).

☐ That a change in a gene that controls cell division can cause a cell to divide uncontrollably, which can result in cancer.

☐ How percentile charts are used to monitor the growth of a child.

Stem Cells

☐ That stem cells are undifferentiated cells that can divide to produce new undifferentiated cells, which can then differentiate.

☐ That embryonic stem cells can produce any type of cell, and that this makes them important for the growth and development of organisms.

☐ That stem cells in adult animals can only produce certain types of cell and are used to replace damaged cells.

☐ That stem cells could be used to create specialised cells to replace faulty cells in medical treatments.

☐ That the use of stem cells in medical treatments carries risks (e.g. tumour development, disease transmission and rejection of transplanted cells), and that some people object to using stem cells for medical treatments and research on ethical grounds.

☐ That plant stem cells are found in tissues called meristems, and that they can differentiate into any type of plant cell throughout the plant's life.

Exam-style Questions

1 **Figure 1** shows four stages of mitosis in a cell. The stages are in the wrong order.

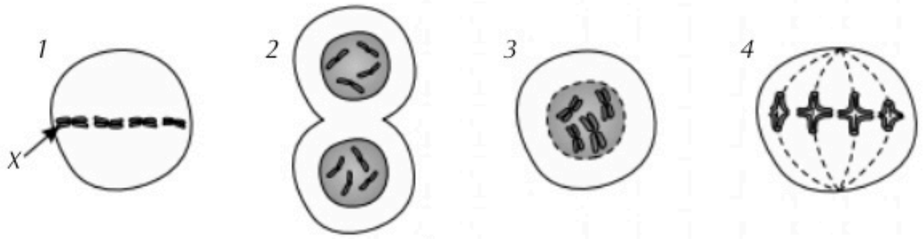


Figure 1

(a) Name the structure labelled **X**.

(1 mark)

(b) Which of the following options lists the stages of mitosis from **Figure 1** in the correct order?

A 1, 2, 4, 3
B 2, 3, 1, 4
C 3, 4, 1, 2
D 3, 1, 4, 2

(1 mark)

(c) Which of the stages shown in **Figure 1** represents prophase? Explain your answer.

(2 marks)

(d) Describe the products of mitosis.

(3 marks)

2 The graph in **Figure 2** is a percentile growth chart for boys aged from 0 to 1 years.

(a) A baby boy who is 9 months old weighs 7.2 kg. What percentile is the baby in?

(1 mark)

(b) A 6-month-old baby boy is in the 50th percentile for weight. Estimate the weight of the baby.

(1 mark)

(c) Describe how a growth chart like the one in **Figure 2** is used to monitor growth.

(2 marks)

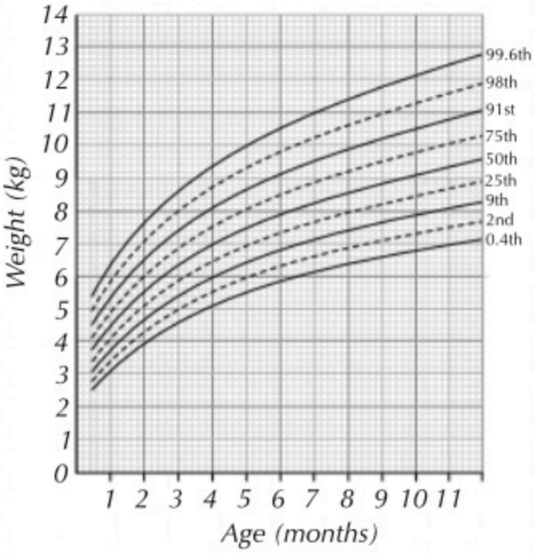


Figure 2

1. The Nervous System

First up, an overview of the nervous system...

What is the nervous system?

Organisms need to respond to **stimuli** (changes in the environment) in order to survive. A single-celled organism can just respond to its environment, but the cells of multicellular organisms need to communicate with each other first. So as multicellular organisms evolved, they developed nervous and hormonal communication systems.

Your nervous system is what allows you to react to your surroundings. It also allows you to coordinate your behaviour. It's made up of all the **neurones** (nerve cells) in your body — there's more on these on the next two pages.

Sensory receptors

Sensory receptors are groups of cells that detect stimuli and initiate responses to them. Different receptors detect different stimuli.

Examples

- Receptors in the eyes detect light.
- Some receptors in the skin detect touch (pressure). Some detect tissue damage (which causes you to feel pain). Others detect temperature change.

The central nervous system (CNS)

The central nervous system (CNS) is where all the information from sensory receptors is sent, and where reflexes (see p.72) and actions are coordinated.

In vertebrates (animals with backbones) the CNS consists of the brain and spinal cord only. The spinal cord is a long column of neurones that runs from the base of the brain down the spine. The spinal cord relays information between the brain and the rest of the body.

In mammals, the CNS is connected to the body by sensory neurones and motor neurones. Neurones transmit information as electrical impulses to and from the CNS. This happens very quickly.

Effectors

'Instructions' from the CNS are sent along neurones to effectors. Effectors are muscles or glands which respond to nervous impulses and bring about a response to a stimulus. Muscles and glands respond to nervous impulses in different ways. Muscles contract and glands secrete chemical substances called hormones (see page 224).

Learning Objective:

- Be able to explain the structure and function of sensory receptors, sensory neurones, relay neurones in the CNS and motor neurones in the transmission of electrical impulses, including the roles of the axon, dendron and myelin sheath.

Specification Reference 2.13

Tip: There's more about hormonal communication on pages 224-226.

Tip: Receptors can form part of larger, complex organs, e.g. the retina of the eye is covered in light receptor cells.

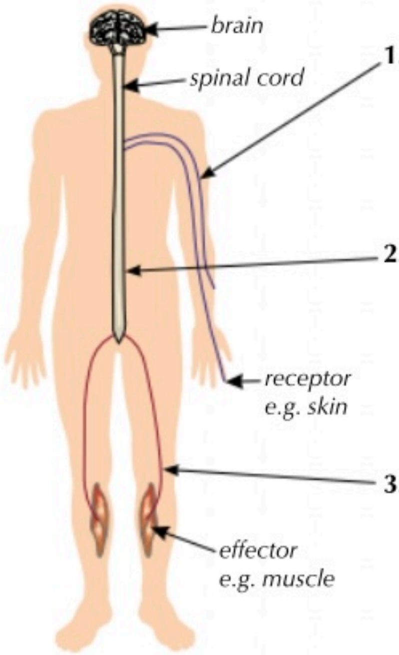
Tip: The CNS coordinates a response — in other words, it receives information about a stimulus and decides what to do about it.

Tip: Nervous impulses are electrical impulses.

Different types of neurone

Different types of neurone are involved in the transfer of information to and from the CNS:

Exam Tip
The exam isn't just a test of what you know — it's also a test of how well you can apply what you know. For instance, you might have to take what you know about a human and apply it to a horse (e.g. sound receptors in its ears send information to the brain via sensory neurones). The key is not to panic — just think carefully about the information that you are given.



1. **Sensory neurones**
   The neurones that carry information as electrical impulses from sensory receptors to the central nervous system.
2. **Relay neurones**
   The neurones that carry electrical impulses from sensory neurones to motor neurones. They are found in the central nervous system.
3. **Motor neurones**
   The neurones that carry electrical impulses from the central nervous system to the effectors.

The transmission of information to and from the CNS is summarised in Figure 1:

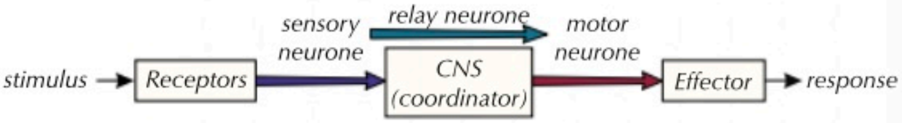


Figure 1: *Flow diagram showing the transmission of information to and from the CNS.*

The time it takes you to respond to a stimulus is called your **reaction time**.

Exam Tip
Make sure you know which type of neurone transfers information to which place in the nervous system — it's easy to get the different types of neurones confused and they often come up in exams.

Neurone structure

All neurones have a cell body with a nucleus (plus cytoplasm and other subcellular structures found in animal cells). The cell body has extensions that connect to other neurones — dendrites and **dendrons** carry nerve impulses towards the cell body, and **axons** carry nerve impulses away from the cell body. Some axons are surrounded by a **myelin sheath**. This is a fatty layer that acts as an electrical insulator, speeding up the electrical impulse.

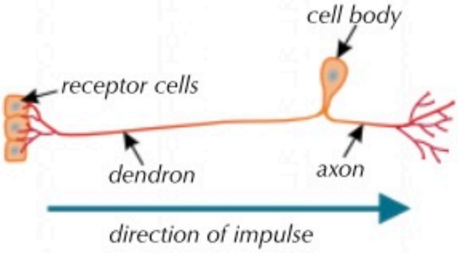
Tip: Remember, axons carry nerve impulses away from the cell body.

Neurones can be very long, which also speeds up the impulse (connecting with another neurone slows the impulse down, so one long neurone is much quicker than lots of short ones joined together).

Structure of a sensory neurone

Sensory neurones have one long dendron that carries nerve impulses from receptor cells to the cell body, which is located in the middle of the neurone. One short axon carries nerve impulses from the cell body to the CNS. See Figure 2 on the next page.

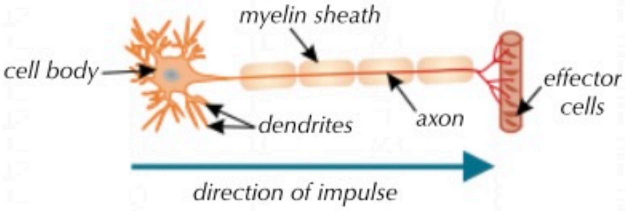
Figure 2: *Diagram showing the structure of a sensory neurone.*


cell body
receptor cells
dendron
axon
direction of impulse

Structure of a motor neurone

Motor neurones have many short dendrites, which carry nerve impulses from the CNS to the cell body. One long axon carries nerve impulses from the cell body to effector cells.

Figure 3: *Diagram showing the structure of a motor neurone.*

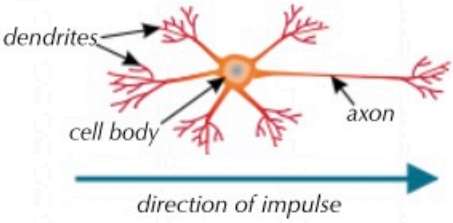

myelin sheath
cell body
effector cells
dendrites
axon
direction of impulse

Tip: Figure 3 shows a myelinated motor neurone but you can get unmyelinated ones too. Sensory and relay neurones can also be myelinated.

Structure of a relay neurone

Relay neurones also have many short dendrites. These carry nerve impulses from sensory neurones to the cell body. An axon carries nerve impulses from the cell body to motor neurones.

Figure 4: *Diagram showing the structure of a relay neurone.*


dendrites
cell body
axon
direction of impulse

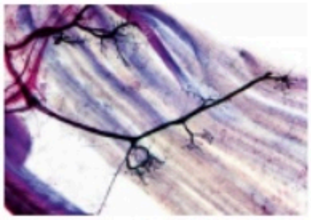


Figure 5: *Motor neurones (black) in muscle tissue, as seen under a light microscope.*

Practice Questions — Fact Recall

Q1 What is the function of an axon?

Q2 Why do some axons have a myelin sheath?

Practice Question — Application

Q1 A dog hears a cat moving in the garden, so runs towards it.

a) i) Suggest what the stimulus is in this situation and what detects it.

ii) What name is given to the type of neurone that transmits information about the stimulus to the central nervous system?

The dog's brain sends an impulse to the dog's muscles which act as effectors.

b) i) What type of neurone transmits information from the central nervous system to an effector?

ii) How do the dog's muscles respond to the nerve impulse?

2. Synapses and Reflexes

Reflexes are rapid responses to stimuli that happen without you having to think about them — they're automatic. The neurones involved in a reflex aren't all joined together though — they have gaps between them called synapses.

Learning Objectives:

- Be able to explain the structure and function of synapses in the transmission of electrical impulses, including the role of neurotransmitters.
- Be able to explain the structure and function of a reflex arc including sensory, relay and motor neurones.

Specification References
2.13, 2.14

Synapses

The connection between two neurones is called a synapse. The nerve signal is transferred by chemicals called **neurotransmitters** which diffuse (move) across the gap. The neurotransmitters then set off a new electrical signal in the next neurone. This is shown in Figure 1.

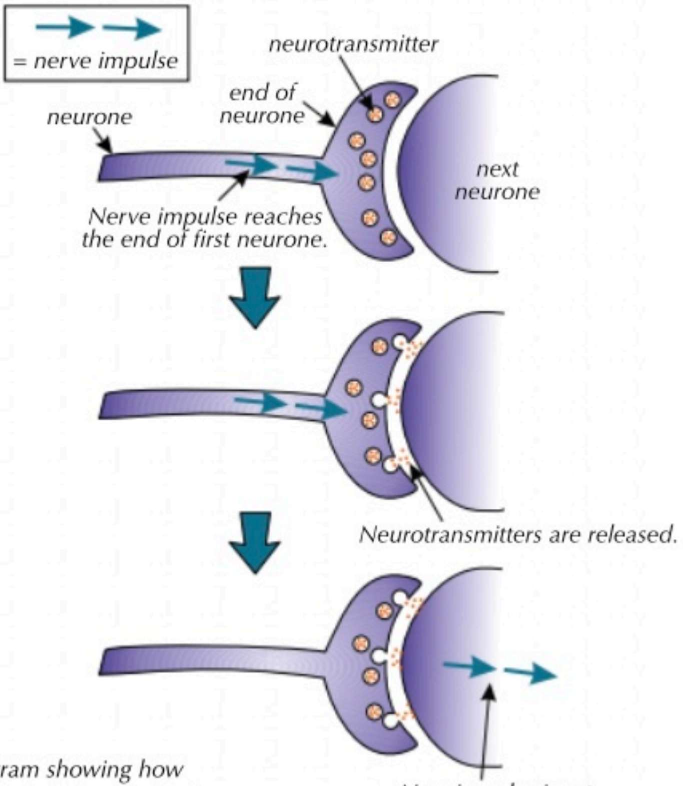

= nerve impulse
neurotransmitter
end of neurone
neurone
next neurone
Nerve impulse reaches the end of first neurone.
Neurotransmitters are released.
New impulse is set off in next neurone.

Figure 1: *Diagram showing how an electrical impulse is transmitted across a synapse.*

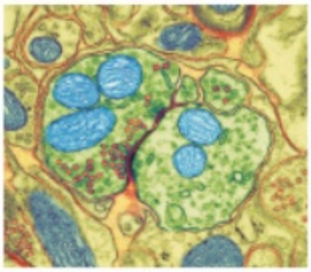


Figure 2: *A synapse viewed under a microscope. The neurones are shown in green. The red dots contain neurotransmitters.*

Neurones deliver information really quickly because the signal is transmitted by electrical impulses. Synapses slow down the transmission of a nervous impulse because the diffusion of neurotransmitters across the gap takes time (it's still pretty fast though).

Reflexes

Reflexes are fast, automatic responses to certain stimuli. They bypass your conscious brain completely when a quick response is essential — your body just gets on with things. Reflexes can reduce your chance of being injured, although they have other roles as well.

Tip: 'Automatic' means done without thinking.

Reflex arcs

The passage of information in a reflex (from receptor to effector) is called a reflex arc. The neurones in reflex arcs go through the spinal cord or through an unconscious part of the brain. Here are the main stages in a reflex arc:

1. When a stimulus is detected by receptors, impulses are sent along a sensory neurone to a relay neurone in the CNS.
2. When the impulses reach a synapse between the sensory neurone and the relay neurone, they trigger neurotransmitters to be released (see previous page). These cause impulses to be sent along the relay neurone.
3. When the impulses reach a synapse between the relay neurone and a motor neurone, the same thing happens. Neurotransmitters are released and cause impulses to be sent along the motor neurone.
4. The impulses then travel along the motor neurone to the effector (which is usually a muscle).
5. If the effector is a muscle, it will respond to the impulse by contracting. If it's a gland, it will secrete a hormone.

Because you don't have to think about the response (which takes time) a reflex is quicker than normal responses. Figure 3 summarises a reflex arc:

Tip: Flick back to pages 70-71 for more on sensory, relay and motor neurones.

Tip: Remember, electrical impulses pass between the different neurones via diffusion of chemicals at the synapse. They don't just jump between the neurones.

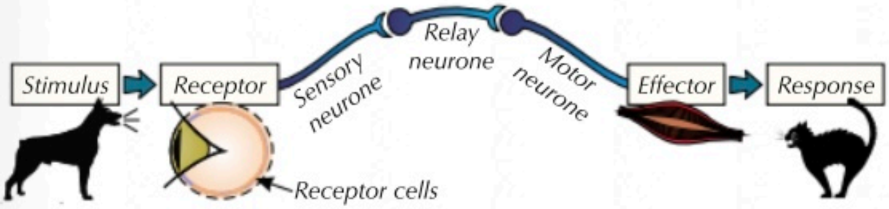
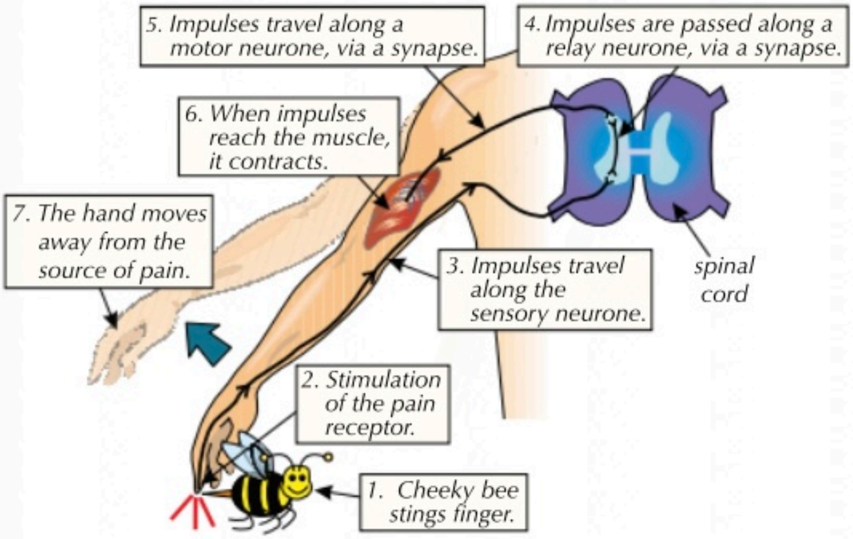

Stimulus
Receptor
Sensory neurone
Relay neurone
Motor neurone
Effector
Response
Receptor cells

Figure 3: *Block diagram of a reflex arc.*

Example

If a bee stings a person's finger, the reflex response is that the hand moves away from the source of pain. Here's the pathway taken by this reflex arc:


5. Impulses travel along a motor neurone, via a synapse.
4. Impulses are passed along a relay neurone, via a synapse.
6. When impulses reach the muscle, it contracts.
7. The hand moves away from the source of pain.
3. Impulses travel along the sensory neurone.
spinal cord
2. Stimulation of the pain receptor.
1. Cheeky bee stings finger.

Tip: The important things to remember about reflexes are that they're automatic (you don't have to think about them) and rapid (so they're often able to prevent or reduce the chance of injury).

Tip: The pupil doesn't actually do anything during the iris reflex — it's just a hole, so although it looks like the pupil is changing size, it's really the iris that's actively doing the changing.

Tip: There's more on the structure of the eye on page 78.

Example

Very bright light can damage the eye — so you have a reflex to protect it, called the iris reflex.

When light receptors in the eye detect very bright light, a message is sent along a sensory neurone to the brain. The message then travels along a relay neurone to a motor neurone, which tells circular muscles in the iris (the coloured part of the eye) to contract, making the pupil smaller. This reduces the amount of light that can enter the eye.

The opposite process happens in dim light. This time, the radial muscles contract and the circular muscles relax, which makes the pupil wider.

This reflex reaction is shown in Figure 4.

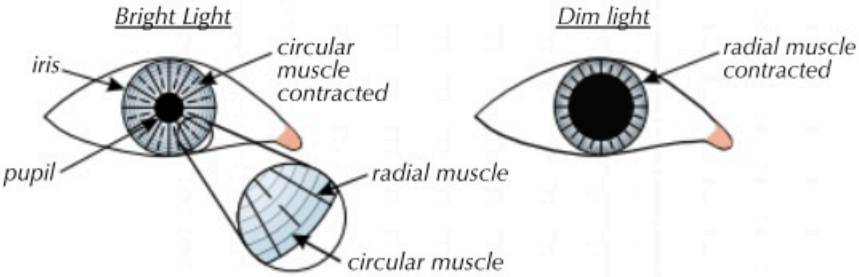


Figure 4: *Diagram showing the iris reflex in bright and dim light.*

Practice Questions — Fact Recall

Q1 How do nerve impulses travel from one neurone to another?

Q2 What is a reflex?

Q3 Do reflex arcs travel through conscious parts of the brain?

Q4 What neurone comes after the sensory neurone in a reflex arc?

Q5 If the effector in a reflex arc is a gland, what will the response of that reflex arc be?

Exam Tip
Questions on reflex arcs are quite common in the exam. Make sure you know the general pathway they take really well, and you'll be able to apply it to any reflex response you're given.

Practice Question — Application

Q1 David steps on a drawing pin and immediately pulls his foot up off the pin.

a) What is the stimulus in this response?

b) What is the effector in this response? How does it respond?

c) Complete the pathway taken by this reflex arc.

Stimulus → Receptor → Sensory neurone...

3. The Brain

The brain is a delicate and complex part of the nervous system. Scientists know a bit about its function, but they'd like to know more.

Brain function

Along with the spinal cord, the brain is part of the central nervous system. It's made up of billions of interconnected neurones (nerve cells that are connected together). The brain is in charge of all of our complex behaviours. It controls and coordinates everything you do — running, breathing, sleeping, remembering your gym kit, etc. We know that different regions of the brain carry out different functions — see below.

Regions of the brain

You need to know the function and location (see Figure 2) of these parts of the brain:

Cerebrum

This is the largest part of the brain. It's divided into two halves called **cerebral hemispheres**. The right hemisphere controls muscles on the left side of the body and the left hemisphere controls muscles on the right side of the body. Different parts of the cerebrum are responsible for different things, including movement, intelligence, memory, language and vision.

Cerebellum

The cerebellum is found at the back of the brain. It's responsible for muscle coordination and balance.

Medulla oblongata

The medulla oblongata is at the base of the brain, at the top of the spinal cord. It controls unconscious activities (things you don't have to think about doing) like breathing and your heart rate.

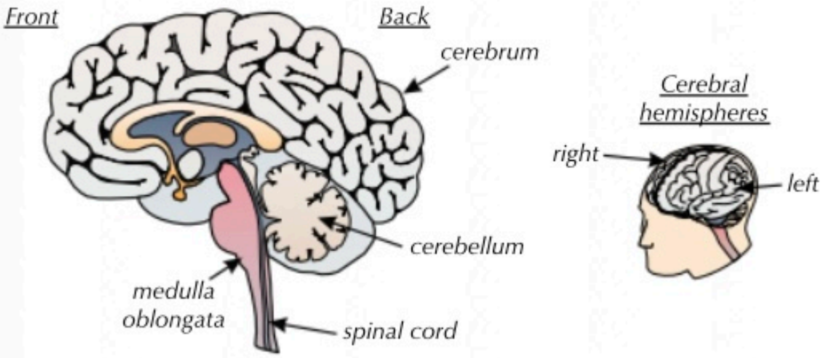


Figure 2: *Regions of the brain.*

Learning Objectives:

- Be able to describe the structures and functions of the brain including the cerebellum, cerebral hemispheres and medulla oblongata.
- **H** Be able to explain how the difficulties of accessing brain tissue inside the skull can be overcome by using CT scanning and PET scanning to investigate brain function.
- **H** Be able to explain some of the limitations in treating damage and disease in the brain and other parts of the nervous system, including spinal injuries and brain tumours.

Specification References
2.10B – 2.12B

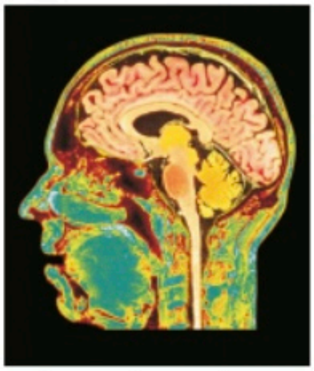


Figure 1: *A scan showing a section through the head. The folded structure at the top (pink) is the outer layer of the cerebrum.*

Tip: The right and left hemispheres in Figure 2 are labelled according to the right and left of the person in the diagram (not your right and left as you look at the picture).

Investigating brain function Higher

To investigate the function of the brain you need to look inside it. Brain tissue can be accessed with surgery (by cutting the skull open), but it's pretty risky. The brain can be visualised without surgery using scanners. For example:

CT scanners

A CT scanner uses X-rays to produce an image of the brain. A CT scan shows the main structures in the brain, but it doesn't show the functions of them.

However, if a CT scan shows a diseased or damaged brain structure and the patient has lost some function, the function of that part of the brain can be worked out.

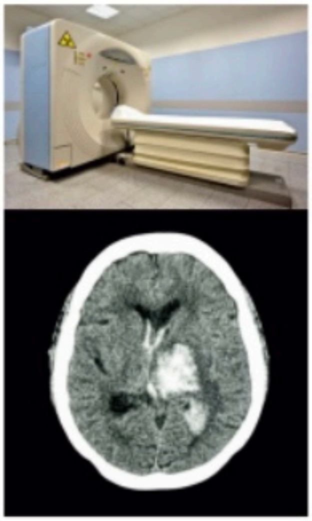


Figure 3: *A CT scanner (top) and a CT image of the brain (bottom). The white area in the centre of the brain indicates damage caused by bleeding.*

Example **Higher**

If an area at the back of the brain is damaged and the patient can't see, then you know that area is involved in vision.

PET scanners

PET scanners are a bit more fancy than CT scanners. Before a person has a PET scan they are injected with a radioactive chemical (called a tracer). The tracer moves around the body and collects in different areas, including the brain. More active cells take up more tracer than less active cells. The person then lies inside the PET scanner and an image is produced, which shows where the tracer has built up. The images can show which parts of the brain are active when the person is inside the scanner.

PET scans are very detailed and can be used to investigate both the structure and the function of the brain in real time. PET scans can show if areas in the brain are unusually inactive or active, so they are useful for studying disorders that change the brain's activity.

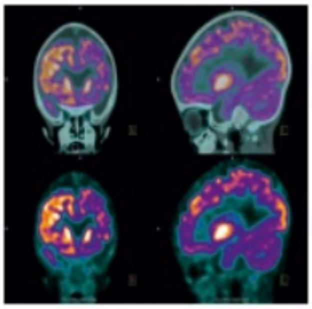


Figure 4: *PET scan images of the human brain. The bright spots show where the radioactive tracer has built up. These are areas of activity.*

Example **Higher**

Alzheimer's disease is a brain disorder. Its main symptom is memory loss. In Alzheimer's disease, activity in certain areas of the brain is reduced — PET scans show this reduction when compared to a normal brain.

Treating problems in the CNS Higher

There are many things that can go wrong with the central nervous system (CNS), e.g. injuries to the brain or spinal cord, tumours, diseases (such as Alzheimer's and Parkinson's). These can be difficult to treat.

One reason for this is that it's hard to repair damage to the nervous system — neurones in the CNS don't readily repair themselves and as of yet scientists haven't developed a way to repair nervous tissue in the CNS.

Another reason is that some parts of the nervous system are not easy to access — particularly the brain. For example, it's not possible to surgically remove tumours growing in certain parts of the brain.

Tip: H A tumour is a mass of abnormal cells (see page 62).

Tip: H Parkinson's disease is another brain disorder. It causes problems with movement, including tremors.

Treatment for problems in the nervous system may also lead to further damage, which could be permanent.

Examples **Higher**

- A person who has injured their spinal cord may need surgery on their spine near to the injury. There is a risk that the spinal cord could be damaged further during the operation, leading to permanent paralysis (loss of movement) because signals from the brain are unable to reach the muscles.
- Doctors may have difficulty removing a brain tumour without leaving surrounding parts of the brain permanently damaged. This damage could lead to problems with the function of those parts of the brain, e.g. speech impairment or problems with vision.

Tip: **H** Scientists are investigating the use of stem cells (see page 64) to replaced damaged neurones in the CNS. This could be a possible treatment for spinal injuries in the future.

Practice Questions — Fact Recall

Q1 Name the region of the brain that is important for memory.

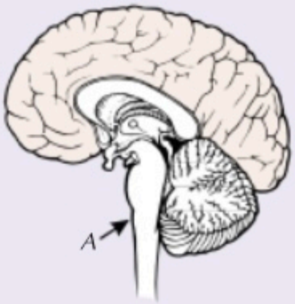
Q2 Where in the brain is the cerebellum located?

Q3 Name two types of scan that scientists can use to study the brain.

Q4 Give three reasons why problems in the CNS may be hard to treat.

Practice Questions — Application

Q1 Name the part of the brain labelled A on the diagram below.



Q2 Ataxia is a brain condition which can cause difficulty with walking. People with ataxia may also have difficulty with tasks that require a lot of muscle control, such as handwriting.

Suggest the part of the brain that may be affected in ataxia.

4. The Eye

The eye is a sense organ — it responds to changes in light (stimuli) by sending messages to the central nervous system. You need to know about several structures of the eye and how they work.

Learning Objectives:

- Be able to explain the structure and function of the eye as a sense organ, including the role of the cornea and lens, the iris, and rod and cone cells (sensory receptors) in the retina.
- Be able to describe defects of the eye including long-sightedness and short-sightedness.
- Be able to explain how long-sightedness and short-sightedness can be corrected.
- Be able to describe defects of the eye including cataracts and colour blindness.
- Be able to explain how cataracts can be corrected.

Specification References
2.15B – 2.17B

Tip: Rods are more sensitive in dim light, but can't detect colour. Cones are sensitive to different colours but are not so good in dim light.

The structure of the eye

The eye has the following parts:

- **Cornea** — the transparent outer layer found at the front of the eye. It refracts (bends) light into the eye.
- **Lens** — refracts light, focusing it onto the retina.
- **Pupil** — the hole in the centre of the eye, through which light enters.
- **Iris** — contains muscles that allow it to control the diameter of the pupil and therefore how much light enters the eye (see page 74).
- **Retina** — the layer at the back of the eye that contains two types of light receptor cells — rods and cones. **Rods** are sensitive to light intensity. **Cones** are sensitive to colour.
- Ciliary muscles and suspensory ligaments — control the shape of the lens.
- Optic nerve — the information from light is converted into electrical impulses by the rods and cones on the retina. The optic nerve carries impulses from these receptors to the brain. It's a sensory neurone.

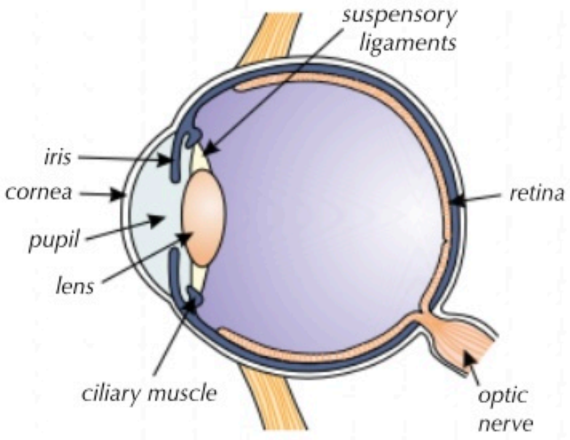


Figure 1: *Structures of the eye.*

Accommodation

The ability to look at near and distant objects is an example of a reflex — it's an automatic reaction, not controlled by the conscious brain (see page 72). The eye focuses light on the retina by changing the shape of the elastic lens. This is known as accommodation.

Looking at near objects

To focus on near objects:

1. The ciliary muscles contract, which slackens the suspensory ligaments.
2. The lens becomes a more rounded shape.
3. This increases the amount by which it refracts light.

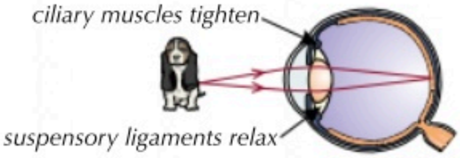


Figure 2: *Diagram showing the changes in the eye to look at a near object.*

Tip: The more rounded the lens is, the more strongly it can refract (bend) rays of light.

Looking at distant objects

To focus on distant objects:

1. The ciliary muscles relax, which allows the suspensory ligaments to pull tight.
2. This pulls the lens into a less rounded shape.
3. So it refracts light by a smaller amount.

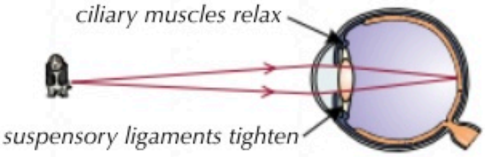


Figure 3: *Diagram showing the changes in the eye to look at a distant object.*

Tip: As you get older, your eye's lens loses flexibility, so it can't easily spring back to a round shape. This means light can't be focused well for near viewing, so older people often have to use reading glasses.

Long- and short-sightedness

To produce a clear image, the light entering the eye needs to be focused on the retina. If the lens cannot focus the light in the correct place, the person will be long- or short-sighted.

Long-sightedness

Long-sighted people are unable to focus on near objects. This occurs when the lens is the wrong shape and doesn't refract the light enough or the eyeball is too short. The images of near objects are brought into focus behind the retina (see Figure 5). You can use glasses or contact lenses with a convex lens (a lens which curves outwards) to correct long-sightedness. The lens refracts the light rays so they focus on the retina.

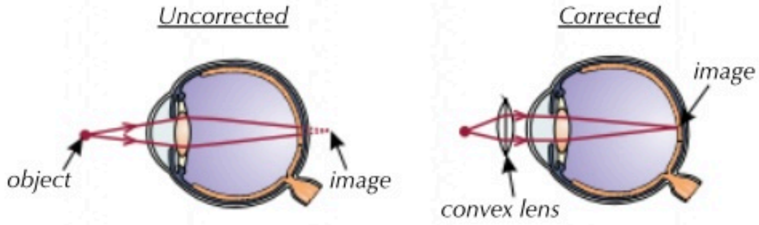


Figure 5: *Diagram showing the focussing of a long-sighted eye before and after a corrective lens is used.*

Figure 4: *Blurred vision caused by long-sightedness. The statue (close up) is out of focus.*

Short-sightedness

Short-sighted people are unable to focus on distant objects. This occurs when the lens is the wrong shape and refracts the light too much or the eyeball is too long. The images of distant objects are brought into focus in front of the retina (see Figure 6). You can use glasses or contact lenses with a concave lens (a lens which curves inwards) to correct short-sightedness, so that the light rays focus on the retina.

Exam Tip
You could be given diagrams like the ones in Figures 5 and 6 in the exam and be asked to explain what's going on.

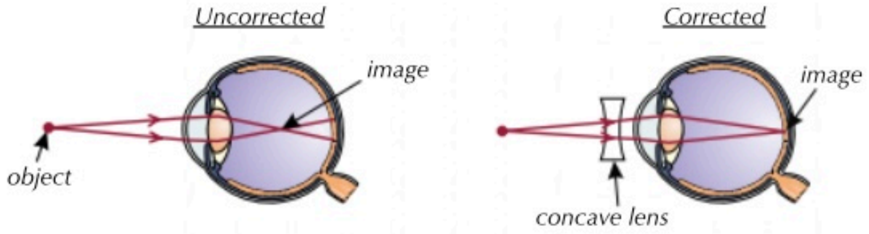


Figure 6: *Diagram showing the focussing of a short-sighted eye before and after a corrective lens is used.*

Other vision problems

Colour blindness

People who are colour blind can't tell the difference between certain colours. The most common form of the disorder is red-green colour blindness — it's caused when red or green cones in the retina are not working properly, so the person is unable to distinguish between red and green (amongst other colours). There's no cure for colour blindness at the moment because the cone cells can't be replaced.

Cataracts

A cataract is a cloudy patch on the lens, which stops light from being able to enter the eye normally. People with cataracts are likely to have blurred vision. They may also experience colours looking less vivid and have difficulty seeing in bright light. A cataract can be treated surgically, by replacing the faulty lens with an artificial one.

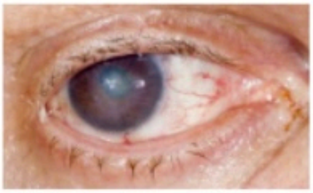


Figure 7: *An eye with an age-related cataract — it has developed over time as the person has aged.*

Practice Questions — Fact Recall

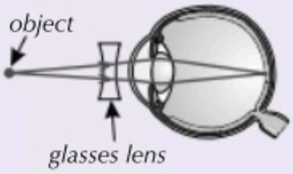
Q1 Name the two parts of the eye that refract light.

Q2 What is the function of the rods and cones in the retina?

Q3 What is a cataract?

Practice Question — Application

Q1 Use the diagram to explain how glasses can help to improve short-sightedness.



Topic 2b Checklist — Make sure you know...

The Nervous System

☐ That sensory receptors are cells that detect stimuli (changes in the environment) and initiate responses.

☐ That the CNS (which is made up of the brain and spinal cord) coordinates responses to stimuli.

☐ That sensory neurones carry nervous (electrical) impulses from sensory receptors to the CNS, relay neurones carry nervous impulses through the CNS and motor neurones carry nervous impulses from the CNS to effectors (muscles and glands).

☐ The structure of sensory, motor and relay neurones, including: the role of the dendron, dendrites and axon in carrying impulses to and away from the cell body, and the role of the myelin sheath in insulating the axon to speed up nervous impulses.

Synapses and Reflexes

☐ The structure of a synapse (the connection between neurones) and how a nerve signal is transferred across a synapse by neurotransmitters.

☐ That in a simple reflex arc, stimuli are detected by receptors and transmitted to the CNS as nervous impulses via sensory neurones. The impulses are then transferred via a relay neurone in the CNS to a motor neurone, which sends impulses to an effector. The effector then produces a response.

The Brain

☐ That the cerebrum is the largest part of the brain and is divided into two cerebral hemispheres. It is responsible for things including movement, intelligence, memory, language and vision.

☐ That the cerebellum is located at the back of the brain and is responsible for muscle coordination and balance.

☐ That the medulla oblongata is found at the base of the brain. It controls unconscious activities.

☐ **H** That accessing the brain via surgery is difficult, and how scientists can overcome this by using CT scans and PET scans to investigate brain function.

☐ **H** Some of the limitations in treating conditions such as brain tumours and spinal injuries.

The Eye

☐ The structure and function of the eye, including: the roles of the cornea and lens in refracting light and focusing it on the retina, the role of the iris in controlling how much light enters the eye and the roles of rod and cone cells as light receptors in the retina.

☐ That long-sightedness is when the eye is unable to focus on nearby objects because the lens is the wrong shape and doesn't refract light enough, and how this can be corrected with lenses.

☐ That short-sightedness is when the eye is unable to focus on distant objects because the lens is the wrong shape and refracts light too much, and how this can be corrected with lenses.

☐ That colour blindness is when people can't tell the difference between certain colours and is caused by cone cells in the eye not functioning properly.

☐ That cataracts are cloudy patches on the lens that result in blurred vision and that they can be corrected by lens replacement surgery.

Exam-style Questions

1 A scientist conducted an experiment on reaction time.

Subjects had an electrode placed on their upper arm to detect when their muscle contracted. The subjects were asked to place their finger on a metal disc, which gave out a small electric shock at random. This shock caused the muscle in the upper arm to contract.

The scientist measured reaction time as the time it took between the initiation of the shock and the contraction of the muscle in the upper arm.

Figure 1 shows the pathway taken in this reflex response.

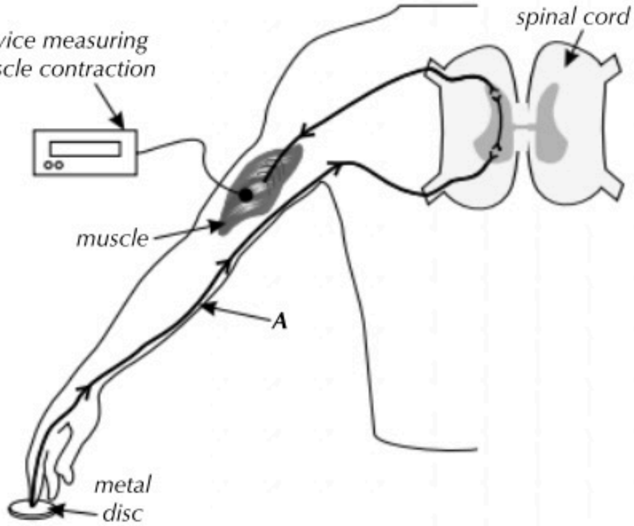


Figure 1

(a) Where are the sensory receptors located in this response?

(1 mark)

(b) Name the type of neurone labelled **A** in the diagram.

(1 mark)

(c) The average reaction time measured during the experiment was 0.024 s.

After he had recorded their reaction times, the scientist gave the subjects a drug which is known to increase the amount of neurotransmitter released at the synapses. He then repeated the experiment.

What do you think would happen to the average reaction time after administration of the drug? Explain your answer.

(2 marks)

(d) Reflexes often help to protect us from injury.
Suggest and explain **two** features of reflexes that help them do this.

(4 marks)

2 A stroke patient has lost the sight in one eye. The stroke happened when the blood supply to the patient's brain was temporarily cut off, resulting in brain damage.

(a) State which region of the patient's brain has been affected by the stroke.

(1 mark)

(b) State **one** way that doctors could confirm which region of the brain has been affected.

(1 mark)

3 A student was investigating the effect of exercise on reaction time.
He measured the reaction times of twenty people using a computer test, in which the person being tested had to click the mouse when a star appeared on the screen.
The participants were then asked to complete five minutes of intense exercise, after which their reaction times were measured again.

The nervous system pathway for the reaction being tested is shown in **Figure 2**.

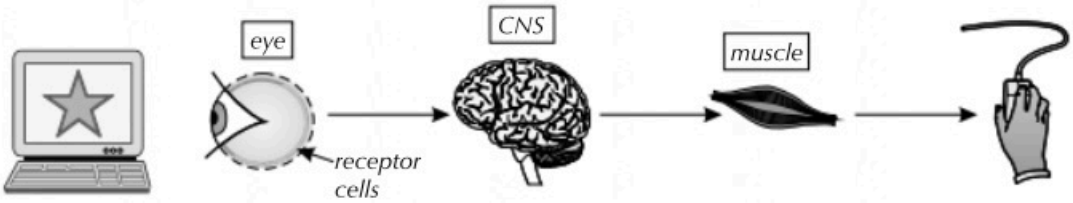


Figure 2

(a) The response in this experiment is coordinated by the brain.
Explain how the brain receives information about the stimulus in this experiment.

(2 marks)

The student summarised the results of the investigation in the histograms in **Figure 3**.

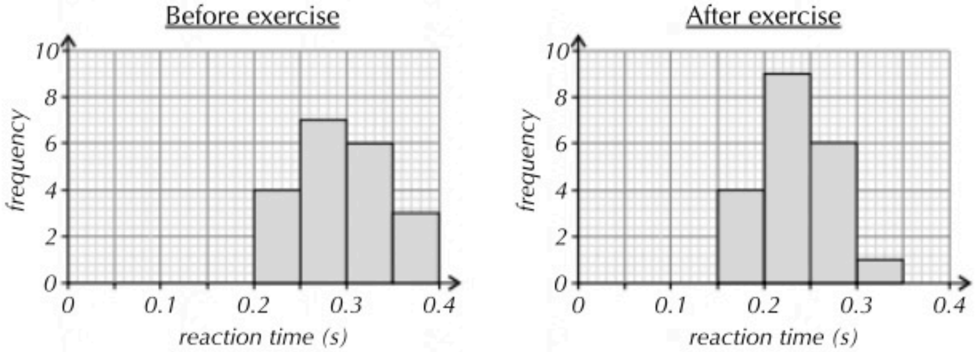


Figure 3

(b) Calculate the difference between the number of people who had a reaction time of less than 0.3 s before exercise and the number who had a reaction time of less than 0.3 s after exercise.

(3 marks)

(c) Give a conclusion about the effect of exercise on reaction time based on these graphs.

(1 mark)

Topic 3a Reproduction, DNA and Protein Synthesis

1. Sexual Reproduction and Meiosis

Learning Objectives:
- Be able to explain the terms gamete and zygote.
- Be able to explain the role of meiotic cell division, including the production of four daughter cells, each with half the number of chromosomes, and that this results in the formation of genetically different haploid gametes.

Specification References 3.3, 3.13

These next two pages are all about how you were made. Read on — it's fascinating stuff...

What is sexual reproduction?

Sexual reproduction is where genetic information from two organisms (a father and a mother) is combined to produce offspring which are genetically different to either parent. Sexual reproduction involves gametes (sex cells).

Gametes

In sexual reproduction the mother and father produce gametes by meiosis (see next page). Egg and sperm cells in animals are examples of gametes (see Figure 1).

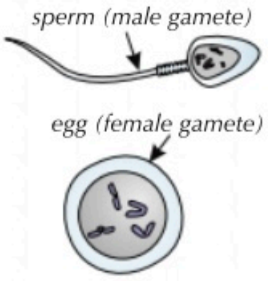


Figure 1: *The sperm and egg cells.*

Normal body cells are **diploid** (see page 58). This means they have two copies of each chromosome. Gametes are **haploid** — they contain half the number of chromosomes in a normal cell (see page 27). So instead of having two copies of each chromosome, a gamete has just one of each.

Tip: In flowering plants, the male gametes are called pollen and the female gametes are called ovules.

Fertilisation

At fertilisation, a male gamete (from the father) fuses with a female gamete (from the mother) to produce a fertilised egg, also known as a **zygote**. The zygote ends up with the full number of chromosomes (half from the father and half from the mother). This is shown in Figure 2.

Tip: The genetic information is stored as DNA in chromosomes — see page 58.

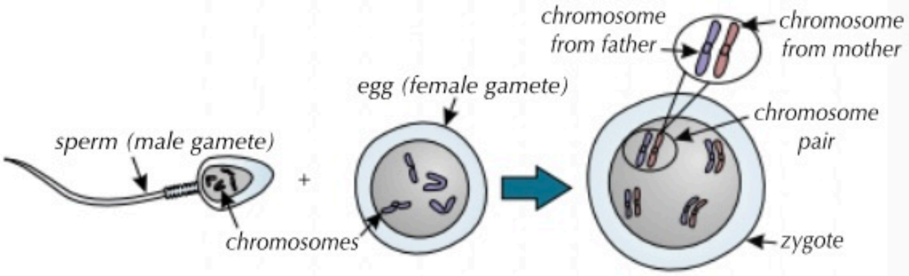


Figure 2: *Diagram showing fertilisation.*

Tip: The zygote is diploid.

The zygote then undergoes cell division (by mitosis, see pages 59-60) and develops into an embryo.

Sexual reproduction means that the offspring inherits features from both parents — it receives a mixture of chromosomes from its mum and its dad (and it's the chromosomes that decide how you turn out). This mixture of genetic information produces variation in the offspring. Pretty cool, eh.

Tip: For more on variation, see pages 117-119.

What is meiosis?

Meiosis is a type of cell division. It's different to mitosis because:

- It doesn't produce identical cells.
- It produces cells which have half the normal number of chromosomes.

Gametes are produced by meiosis. In humans, meiosis only takes place in the reproductive organs (ovaries and testes).

Exam Tip
The words 'mitosis' and 'meiosis' look and sound very similar. Make sure that you know how to spell each one. You won't gain marks in the exam if the examiner can't tell which type of cell division you are talking about.

Cell division by meiosis

1. Before the cell starts to divide, it duplicates its genetic information, forming two armed chromosomes — one arm of each chromosome is an exact copy of the other arm. After replication, the chromosomes arrange themselves into pairs.
2. In the first division in meiosis the chromosome pairs line up in the centre of the cell.
3. The pairs are then pulled apart so each new cell only has one copy of each chromosome. Some of the father's chromosomes (shown in blue in Figure 4) and some of the mother's chromosomes (shown in red) go into each new cell. This mixing up of the parents' chromosomes is really important — it mixes up their genes, creating genetic variation in the offspring.
4. In the second division, the chromosomes line up again in the centre of the cell. The arms of the chromosomes (called chromatids) are pulled apart.
5. You get four haploid daughter cells — these are the gametes. Each gamete only has a single set of chromosomes in it. Each of the gametes (sperm or egg cells) is genetically different from the others.

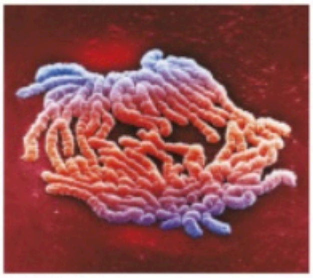


Figure 3: *Microscope image showing pairs of chromosomes being pulled apart during the first division in meiosis.*

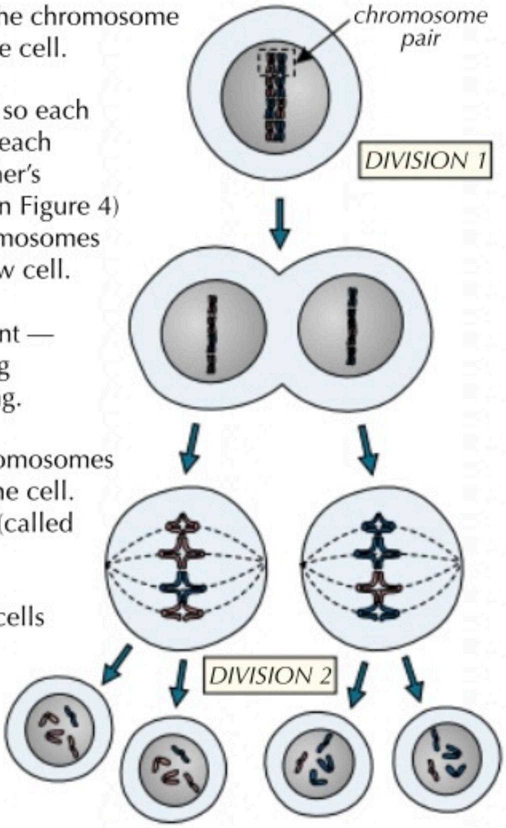


Figure 4: *Diagram showing the stages in meiosis.*

Practice Questions — Fact Recall

Q1 How many sets of chromosomes do gametes contain?

Q2 Where are gametes produced?

Q3 How many cell divisions occur in meiosis?

Q4 How many new cells are produced when a cell divides by meiosis?

Q5 True or False? Gametes are all genetically identical.

Practice Questions — Application

Q1 Different animals have different numbers of chromosomes in their body cells and in their gametes, as shown in the table:

Type of animal cell	Number of chromosomes
Dog body cell	78
Cat egg cell	19
Horse sperm cell	32

Using your knowledge and the information provided in the table, suggest:

a) how many chromosomes there are in a dog sperm cell.

b) how many chromosomes there are in the body cell of a cat.

c) how many chromosomes there are in a horse egg cell.

Q2 Mary thinks that after the first division in meiosis, cells will have half a set of chromosomes. Why does this not happen after the first division when a cell divides by meiosis?

2. Asexual and Sexual Reproduction

Reproduction allows organisms to pass on their DNA. Not all organisms reproduce using sexual reproduction — some use asexual reproduction instead (and some do both). There are advantages and disadvantages to each method.

Learning Objectives:

- Be able to explain some of the advantages and disadvantages of asexual reproduction, including the lack of need to find a mate, a rapid reproductive cycle, but no variation in the population.
- Be able to explain some of the advantages and disadvantages of sexual reproduction, including variation in the population, but the requirement to find a mate.

Specification References
3.1B, 3.2B

Types of reproduction

Asexual reproduction involves only one parent, so the offspring are genetically identical to that parent. Asexual reproduction happens by mitosis — an ordinary cell divides in two to make two new cells (see pages 59-60). The new cells are genetically identical to each other and to the parent cell.

This is in contrast to **sexual reproduction** (see pages 84-85) which involves two parents. Meiosis is used to produce two genetically different haploid gametes, which fuse to form a diploid cell at fertilisation.

Advantages of asexual reproduction

Asexual reproduction has advantages over sexual reproduction.

As there only needs to be one parent, the **reproductive cycle** (the time it takes to produce independent offspring) is much faster for asexual reproduction than it is for sexual reproduction. This means that asexual reproduction can produce lots of offspring very quickly.

Another advantage is that organisms can reproduce whenever conditions are favourable, without having to wait for a mate. These advantages allow organisms to colonise a new area very rapidly.

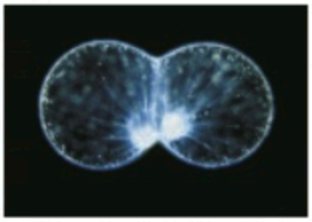


Figure 1: *A single-celled organism called a 'sea sparkle' undergoing asexual reproduction.*

Example

Dandelion plants are able to reproduce asexually. When conditions in the environment are ideal for growth, being able to produce many identical offspring quickly means that the dandelions can spread fast to take over an area.

Disadvantages of asexual reproduction

There are disadvantages to asexual reproduction though.

There's no genetic variation between offspring in a population created through asexual reproduction. So if the environment changes and conditions becomes unfavourable, the whole population may be unable to cope.

Tip: Asexual reproduction happens in different ways. E.g. strawberry plants produce runners (see page 60). Daffodils produce bulbs that split in two. Some lizards can produce eggs that don't need to be fertilised.

Example

Black Sigatoka is a disease that affects banana plants, which usually reproduce asexually. So if there's an outbreak of the disease, it's likely that all banana plants in the population will be affected as there are none that are resistant to it. Black Sigatoka is causing problems for farmers who grow bananas for people to eat.

Advantages of sexual reproduction

Sexual reproduction has advantages over asexual reproduction.

Offspring from sexual reproduction have a mixture of two sets of chromosomes. The organism inherits genes (and therefore features) from both parents, which produces genetic variation in the offspring (see p.117).

Variation increases the chance of a species surviving a change in the environment. While a change in the environment could kill some individuals, it's likely that variation would result in some of the offspring being able to survive in the new environment. They have a survival advantage. Individuals with characteristics that make them better adapted to the environment have a better chance of survival, so they are more likely to breed successfully and pass the genes for the characteristics on. This is known as natural selection and it can lead to evolution (see p.125).

Disadvantages of sexual reproduction

Sexual reproduction has disadvantages too.

Organisms need to find and attract mates in order to reproduce sexually. This means that sexual reproduction takes more time and energy than asexual reproduction.

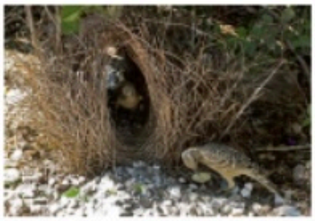


Figure 2: *A bowerbird, his mate and the 'bower' (structure made from twigs) he has built to impress her.*

Example

Male bowerbirds build structures out of twigs and then dance to impress females. Only the males with the most impressive displays get to mate.

This means that sexually reproducing organisms tend to produce fewer offspring in their lifetime than asexually reproducing organisms.
The need to find a mate can also be a problem if individuals are isolated.

Example

Polar bears often live alone, so male polar bears may have to walk up to 100 miles to find a mate.

Practice Question — Application

Q1 Two species of lizard live in a semi-arid area. One species of lizard only reproduces asexually. The other species reproduces sexually. Over a few years, the climate changes to become much hotter and drier and the local vegetation changes.

a) Explain which lizard species is more likely to survive the climate change in the area.

b) A small population of each lizard species is moved to a new area where conditions are favourable. Suggest which species is most likely to colonise the new area in the shortest time. Explain your answer.

Tip: 'Semi-arid' means 'semi-dry'. A semi-arid area is usually a grassland area with some rainfall.

3. DNA

DNA is a pretty important molecule because it's what makes us unique. Therefore it's really important that you learn all about it...

Chromosomes and DNA

DNA stands for deoxyribonucleic acid. It's the chemical that all of the genetic material in a cell is made up from. It contains coded information — basically all the instructions to put an organism together and make it work. So it's what's in your DNA that determines what inherited characteristics you have.

DNA is found in the nucleus of eukaryotic cells (e.g. animal and plant cells), in really long structures called chromosomes. The DNA is coiled up to form the 'arms' of the chromosome. In diploid cells, chromosomes come in pairs.

DNA is a polymer — a large molecule built from a chain of smaller molecules. As you can see from Figure 1, DNA is made up of two strands twisted together in the shape of a double helix.

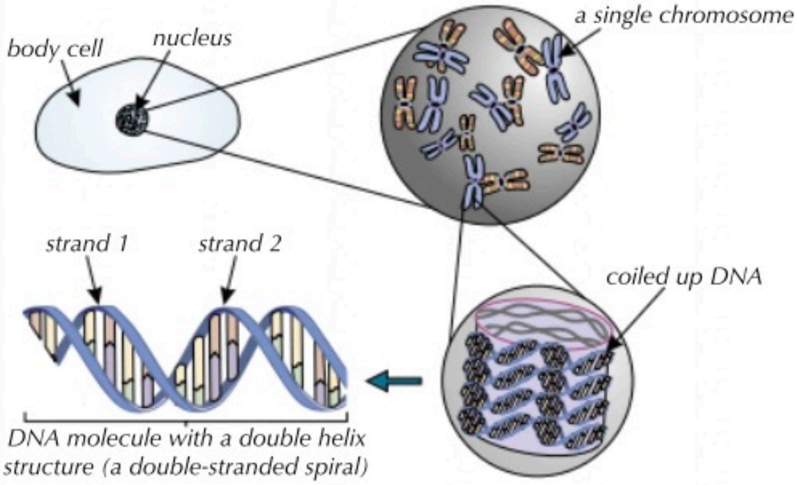

a single chromosome
body cell
nucleus
strand 1
strand 2
coiled up DNA
DNA molecule with a double helix structure (a double-stranded spiral)

Figure 1: *Diagram showing the structure of DNA and where it is found in a eukaryotic cell.*

Genes and the genome

A **gene** is a small section of DNA. Each gene codes for (tells the cells to make) a particular sequence of amino acids which are put together to make a specific protein.

All of an organism's DNA makes up its **genome**.

Learning Objectives:

- Be able to explain the term chromosome.
- Be able to describe DNA as a polymer made up of two strands coiled to form a double helix.
- Be able to describe a gene as a section of a DNA molecule that codes for a specific protein and the genome as the entire DNA of an organism.
- Be able to describe DNA as a polymer made up of:
  - nucleotides that consist of a sugar and phosphate group with one of the four different bases attached to the sugar,
  - strands linked by a series of complementary base pairs joined together by weak hydrogen bonds.
- Be able to explain how DNA can be extracted from fruit.

Specification References
3.4 – 3.6, 3.13

Tip: Chromosomes in bacteria are different to chromosomes in eukaryotic cells. Bacteria have one big loop of chromosomal DNA in their cytoplasm — see p.24 for more.

The structure of DNA

Nucleotides

DNA strands are polymers made up of lots of repeating units called nucleotides. There are four different nucleotides — each nucleotide consists of a sugar, a phosphate group and one of four different 'bases'. The sugars and phosphate groups in the nucleotides form a 'backbone' to the DNA strands. The sugars and phosphate groups alternate. The four different bases are A (adenine), T (thymine), C (cytosine) and G (guanine) — one joins to each sugar.

Exam Tip
As well as remembering what a nucleotide is made up of, make sure you know how the components join together — the base is always attached to a sugar, and the sugar is attached to a phosphate group.

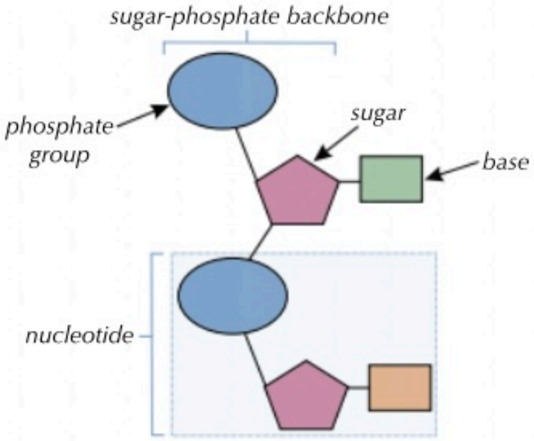

sugar-phosphate backbone
phosphate group
sugar
base
nucleotide

Figure 2: *Diagram showing part of a DNA strand.*

Complementary base pairing

Each base in a DNA strand links to a base on the opposite strand in the helix — see Figure 3.

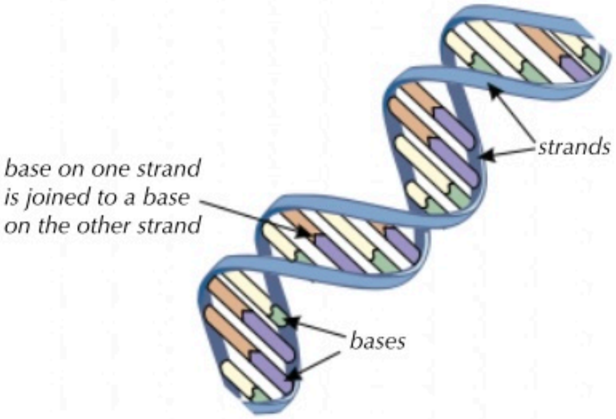

strands
base on one strand is joined to a base on the other strand
bases

Figure 3: *Diagram showing part of a DNA molecule.*

A always pairs up with T, and C always pairs up with G (see Figure 4 on the next page). This is called complementary base pairing. The complementary base pairs are held together by weak hydrogen bonds.

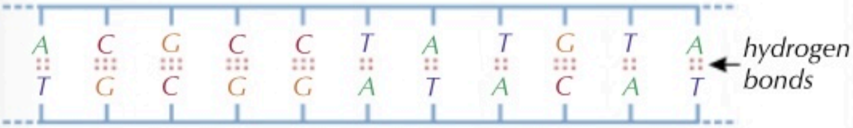

A C G C C T A T G T A
T G C G G A T A C A T
hydrogen bonds

Figure 4: *Diagram showing complementary pairing of bases in DNA.*

Exam Tip
Make sure you memorise which bases link with which — it could be easy marks in the exam.

Extracting DNA from fruit

You need to be able to describe how to extract DNA from fruit. Here's what you do:

1. Mash some strawberries and then put them in a beaker containing a solution of detergent and salt. Mix well.
   - The detergent will break down the cell membranes to release the DNA.
   - The salt will make the DNA stick together.
2. Filter the mixture to get the froth and big, insoluble bits of cell out.
3. Gently add some ice-cold alcohol (e.g. ethanol) to the filtered mixture.
4. The DNA will start to come out of solution as it's not soluble in cold alcohol. It will appear as a stringy white precipitate (a solid) that can be carefully fished out with a glass rod (see Figure 5).

Tip: Always do a risk assessment before carrying out any practical work.

Tip: Other soft fruits will work well here, such as kiwi or banana. You can use washing up liquid as the detergent.

Tip: DNA isn't soluble in alcohol — so adding the alcohol causes the DNA to precipitate out of the solution.

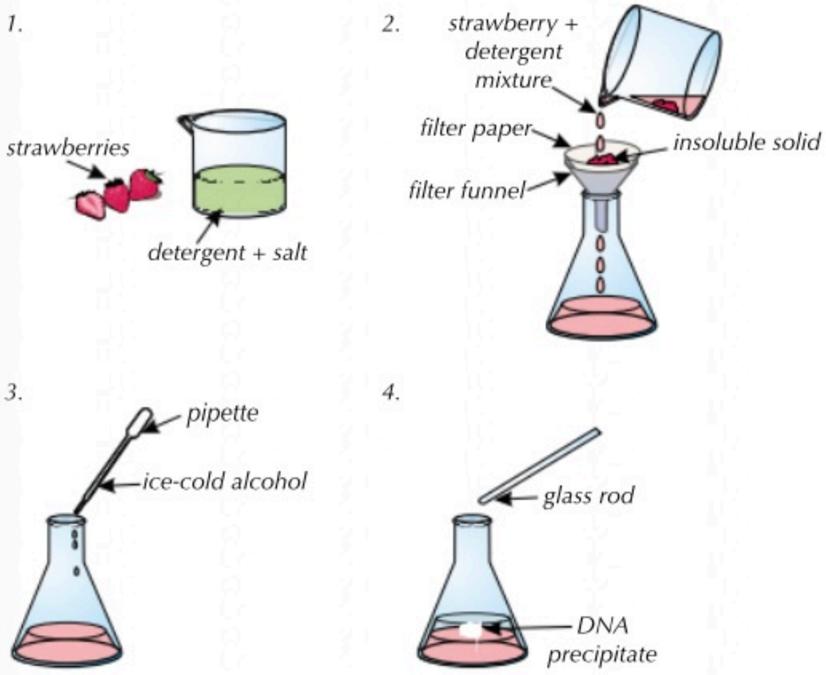

1.
strawberries
detergent + salt
2.
strawberry + detergent mixture
filter paper
insoluble solid
filter funnel
3.
pipette
ice-cold alcohol
4.
glass rod
DNA precipitate

Figure 5: *Diagram showing method for extracting DNA from strawberries.*

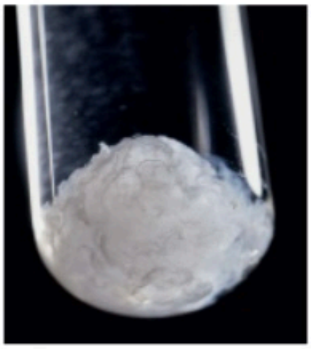


Figure 6: *If you're careful, the DNA precipitate you extract from your fruit should look something like this.*

Practice Questions — Fact Recall

Q1 What is a DNA double helix?

Q2 What term is used to describe:

a) A section of DNA that codes for a particular protein?

b) All of an organism's DNA?

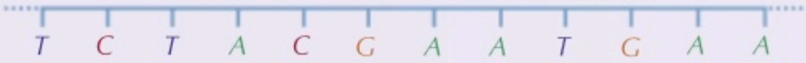
Q3 a) What is a nucleotide made up of?

b) Which parts of a nucleotide alternate to form the backbone of a DNA strand?

Q4 What holds the complementary base pairs together in DNA?

Practice Questions — Application

Q1 A DNA sequence is shown below.
Write the base sequence for the complementary strand.



Q2 A student is extracting DNA from a kiwi fruit. She mashes up the fruit to form a pulp and adds a solution of washing-up liquid.

a) Why does the student add the washing-up liquid solution to the fruit pulp?

b) What does the student need to add to make the DNA clump together?

c) After filtering her mixture, the student adds ice-cold alcohol. Describe what the student should expect to see after carrying out this step.

4. Protein Synthesis Higher

Proteins are chains of amino acids. Your genes contain the instructions your cells need to make proteins.

Making proteins

DNA controls the production of proteins (protein synthesis) in a cell. Proteins are made up of chains of molecules called **amino acids**. Each different protein has its own particular number and order of amino acids.

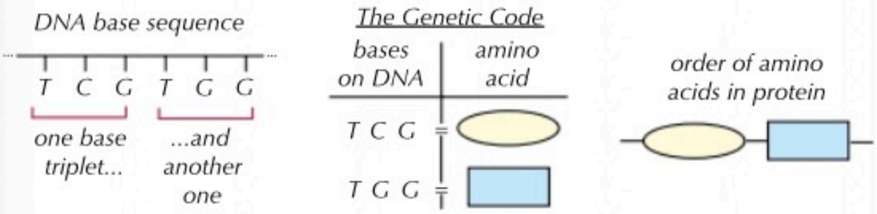
The amino acid chains fold up to give each protein a different, specific shape — which means each protein can have a different function. This is why enzymes have active sites with a specific shape, and so only catalyse a specific reaction (see page 36).

A section of DNA that codes for a particular protein is called a **gene** (see page 89). It's the order of the bases in a gene that decides the order of amino acids in a protein.

Each amino acid is coded for by a sequence of three bases in the gene — this is called a **base triplet**. The amino acids are joined together to make proteins, following the order of the bases in the gene (see Figure 1). Each gene contains a different sequence of bases — which is what allows it to code for a particular protein.

Example **Higher**

Using the sequence of bases below on the left, the cell reads the genetic code to put the amino acids together.



Non-coding parts of DNA

Many regions of DNA are non-coding — that means that they don't code for any amino acids. Some of these non-coding parts switch genes on and off, so they control whether or not a gene is expressed (used to make a protein). There's more on this on page 97. All of an organism's DNA (including the non-coding regions) makes up the organism's genome.

Mutations and genetic variants

A mutation is a rare, random change to an organism's DNA base sequence that can be inherited. If a mutation happens in a gene, it produces a genetic variant — a different version of the gene.

The genetic variant may code for a different sequence of amino acids.

Learning Objectives:

- H Be able to explain how the order of bases in a section of DNA decides the order of amino acids in the protein and that these fold to produce specifically shaped proteins such as enzymes.
- H Be able to describe how genetic variants in the coding DNA of a gene can affect phenotype by altering the sequence of amino acids and therefore the activity of the protein produced.

Specification References
3.7B, 3.10B

Tip: H A code based on base triplets is called a triplet code.

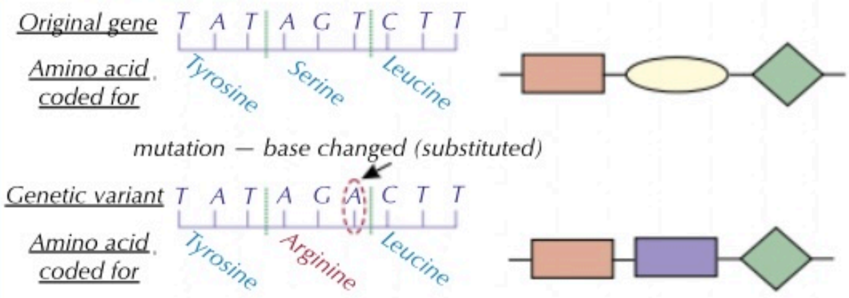
Exam Tip H
You don't need to learn the names of any amino acids or which base triplets code for each amino acid.

Tip: H Base triplets don't overlap.
So the code:
TCGAATTCA is read TCG, AAT, TCA, not TCG, CGA, GAA, etc.

Tip: H Genetic variants are also called alleles — see page 101.

Tip: **H** Mutations can also involve bases being deleted or added to the base sequence. This can result in changes to several amino acids. However, bases can sometimes be substituted without changing the amino acid sequence because most amino acids are coded for by more than one base triplet.

Example **Higher**


Original gene
T A T A G T C T T
Amino acid coded for
Tyrosine
Serine
Leucine
mutation — base changed (substituted)
Genetic variant
T A T A G A C T T
Amino acid coded for
Tyrosine
Arginine
Leucine

The change in the amino acid sequence may change the shape of the final protein, and so its activity will also change. For example, the activity of an enzyme might increase, decrease or stop altogether. This could end up changing the characteristics (also known as the phenotype, see p.101) of an organism.

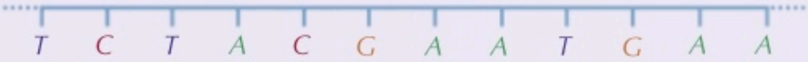
Example **Higher**

XDH is an enzyme. Fruit flies with normal XDH activity have red eyes. Fruit flies with no XDH activity have brown eyes because they can't produce the red eye pigment.

Mutations can also happen in non-coding regions of DNA. There's more on the influence of variants in non-coding DNA on page 97.

Practice Questions — Application

Q1 Use the table to determine the amino acids that are coded for by the base sequence below.


T C T A C G A A T G A A

Base Sequence	Amino Acid
AAT	Asparagine
TCT	Serine
GTC	Valine
TGG	Tryptophan
TTT	Phenylalanine
GAA	Glutamic acid
ACG	Threonine
CCA	Proline

Q2 Humans produce an enzyme that converts the amino acid phenylalanine into another amino acid called tyrosine. People with the inherited disorder PKU cannot convert phenylalanine into tyrosine. Explain how a mutation in a gene could cause PKU.

5. More on Protein Synthesis **Higher**

There's a lot of work involved in making a protein...

How are proteins made?

Proteins are made in two stages. The first stage of protein synthesis is called **transcription**. It takes place in the cell nucleus. The second stage is called **translation**. It takes place in the cell cytoplasm and involves subcellular structures called ribosomes (see p.23). Ribosomes join amino acids together to make a protein.

Transcription

DNA is stored in the cell nucleus. It can't move out of the nucleus because it's really big. So to make a protein, the cell needs to get the information in DNA to a ribosome in the cytoplasm.

This is done using a molecule called **messenger RNA** (**mRNA**). Like DNA, mRNA is a polymer of nucleotides, but it's shorter and only a single strand. It also uses uracil (U) instead of thymine (T) as a base.

mRNA is made by copying the DNA base sequence of a gene — this is transcription. An enzyme called **RNA polymerase** joins together RNA nucleotides to make the mRNA.

Here's how it works:

1. RNA polymerase binds to a region of non-coding DNA in front of a gene.

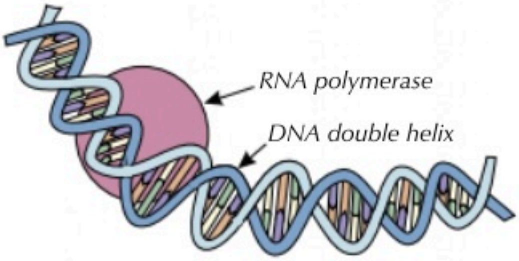


Figure 1: *RNA polymerase binds to DNA.*

2. The two DNA strands unzip and the RNA polymerase moves along one of the strands of the DNA. It uses the coding DNA in the gene as a template to make the mRNA. Base pairing between the DNA and RNA ensures that the mRNA is complementary to the gene.

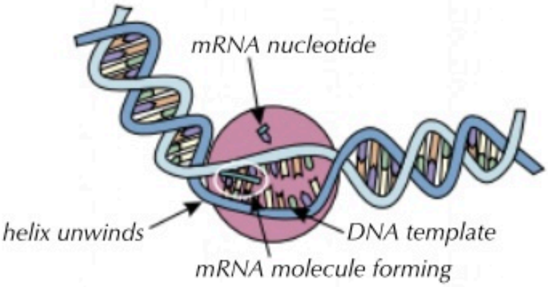


Figure 2: *RNA polymerase moves along the DNA and the mRNA is assembled.*

Learning Objectives:

- **H** Be able to describe the stages of protein synthesis, including transcription and translation:
  - **H** RNA polymerase binds to non-coding DNA located in front of a gene;
  - **H** RNA polymerase produces a complementary mRNA strand from the coding DNA of the gene;
  - **H** the attachment of the mRNA to the ribosome;
  - **H** the coding by triplets of bases (codons) in the mRNA for specific amino acids;
  - **H** the transfer of amino acids to the ribosome by tRNA;
  - **H** the linking of amino acids to form polypeptides.
- **H** Be able to describe how genetic variants in the non-coding DNA of a gene can affect phenotype by influencing the binding of RNA polymerase and altering the quantity of protein produced.

Specification References
3.8B, 3.9B

Tip: **H** During complementary base pairing between mRNA and DNA, Uracil (U) pairs with adenine (A). There's more on complementary base pairing on pages 90-91.

3. Once made, the mRNA molecule moves out of the nucleus and joins with a ribosome in the cytoplasm.

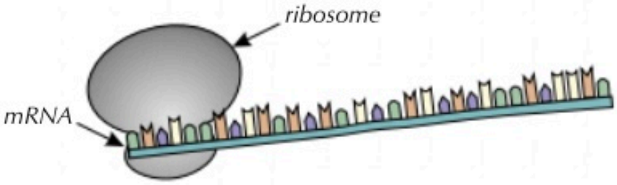


Figure 3: *mRNA attaches to a ribosome.*

Translation

Once the mRNA is bound to a ribosome, the protein can be assembled. This stage is translation. Here's how it works:

1. Amino acids are brought to the ribosome by another RNA molecule called **transfer RNA** (**tRNA**).
2. The order in which the amino acids are brought to the ribosome matches the order of the base triplets in mRNA. Base triplets in mRNA are also known as **codons**.
3. Part of the tRNA's structure is called an **anticodon** — it is complementary to the codon for the amino acid. The pairing of the codon and anticodon makes sure that the amino acids are brought to the ribosome in the correct order.

Tip: H An anticodon is the opposite of a codon.

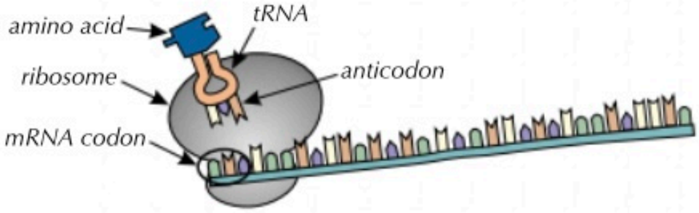


Figure 4: *A tRNA molecule brings an amino acid to the ribosome.*

Exam Tip H
Make sure you learn all the technical terms to do with transcription and translation, e.g. RNA polymerase, mRNA, tRNA, codon, etc. You'll need to be able to use them correctly to pick up full marks in exam questions on protein synthesis.

4. The amino acids are joined together by the ribosome. This makes a **polypeptide** (protein). Once they have deposited their amino acid, empty tRNA molecules move away again.

Tip: H A polypeptide is a chain of amino acids. It's basically just another word for a protein (although some proteins have more than one polypeptide chain).

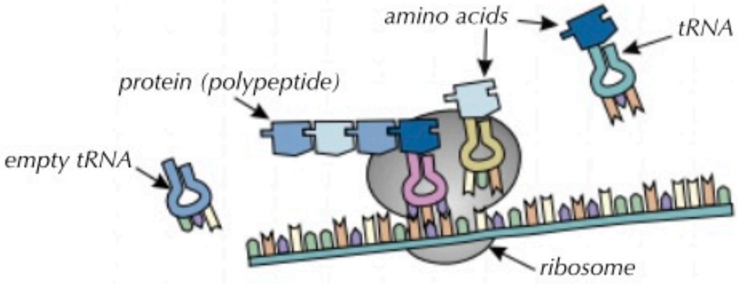


Figure 5: *A protein is assembled.*

Variants in non-coding DNA

You might remember from page 93 that a mutation (change to the DNA base sequence) in a gene can create a genetic variant that leads to changes in an organism's phenotype (characteristics). Variants in non-coding regions of DNA can also affect the phenotype of an organism, even if they don't code for proteins themselves.

This is because, before any transcription can happen, RNA polymerase has to bind to a region of non-coding DNA in front of a gene (see p.95). If a mutation happens in this region of DNA, then it could affect the ability of RNA polymerase to bind to it. It might make it easier to bind to, or more difficult.

How well RNA polymerase can bind to this region of DNA will affect how much mRNA is transcribed and therefore how much of the protein is produced. And, depending on the function of the protein, the phenotype of the organism may be affected by how much of it is made.

Tip: **H** The enzyme lactase breaks down lactose — the sugar in milk. Some people have a mutation in the non-coding DNA before the lactase gene that allows them to produce lactase as adults. Adults who don't have this mutation can't produce lactase and are lactose-intolerant.

Practice Questions — Fact Recall

Q1 Describe the role of mRNA in transcription.

Q2 mRNA nucleotides are assembled according to a DNA template. What is the name of the enzyme that assembles them?

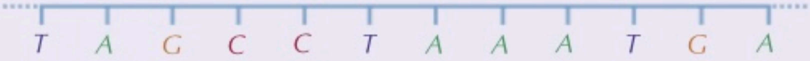
Q3 Describe the role of tRNA in translation.

Q4 What is an mRNA codon?

Q5 Name the structure responsible for joining amino acids together to make a polypeptide.

Practice Questions — Application

Q1 A DNA sequence is shown below.
Write the mRNA base sequence that would be produced from it.



Q2 Sometimes cancer is caused because a particular gene is "switched off". This means the protein it codes for stops being made. Suggest and explain how a mutation could lead to a gene being switched off.

Topic 3a Checklist — Make sure you know...

Sexual Reproduction and Meiosis

☐ That gametes (sex cells) are haploid (they have half the number of chromosomes in normal body cells).

☐ That a zygote (fertilised egg) is formed when two gametes fuse together at fertilisation.

☐ That gametes are produced by meiosis — a type of cell division that results in four genetically different haploid daughter cells.

cont...

Asexual and Sexual Reproduction

☐ Some advantages of asexual reproduction over sexual reproduction — because there's only one parent in asexual reproduction, there's no need to expend energy finding a mate and the reproductive cycle is quicker than for sexual reproduction.

☐ That the major disadvantage of asexual reproduction compared to sexual reproduction is that there is no variation in a population produced by asexual reproduction, which might make it vulnerable to a change in the environment, e.g. the appearance of a new disease.

☐ That the major advantage of sexual reproduction over asexual reproduction is that it introduces genetic variation into a population, which may help it to better withstand environmental change, but that it is does require more energy as a mate has to be found.

DNA

☐ That DNA is stored in the cell nucleus as chromosomes (long molecules of coiled-up DNA).

☐ That DNA is a polymer made up of two strands twisted into a double-helix shape.

☐ That a gene is a section of DNA that codes for a particular protein and that the genome is all the DNA in an organism.

☐ That DNA is made up of nucleotides, each containing a sugar, a phosphate group and one of four different bases (A, T, C and G) attached to the sugar.

☐ That the two strands in a DNA double helix are linked by complementary base pairs (A–T and C–G) held together by weak hydrogen bonds.

☐ How to extract DNA from fruit, using detergent, salt, filter paper and ice-cold alcohol to precipitate out the DNA.

Protein Synthesis

☐ **H** That chains of amino acids fold up to make proteins, each with a specific shape.

☐ **H** How the specific shape of proteins (e.g. enzymes) allows them to carry out their function.

☐ **H** How the order of bases in a gene determines the order of amino acids in a protein — each amino acid is coded for by a sequence of three bases called a base triplet.

☐ **H** That a mutation (change to the DNA base sequence) in the coding DNA of a gene can create a genetic variant (an alternative version of the gene).

☐ **H** How genetic variants can alter the amino acid sequence and therefore the protein that gets produced, and how this may alter an organism's phenotype by altering the protein's activity.

More on Protein Synthesis

☐ **H** How, in the first stage of protein synthesis (transcription), a gene is copied from DNA into mRNA using the enzyme RNA polymerase. The completed mRNA then attaches to a ribosome.

☐ **H** How, in the second stage of protein synthesis (translation), tRNA brings amino acids to the ribosome in the order determined by the codons in mRNA and that the amino acids are joined together by the ribosome to form a polypeptide (protein).

☐ **H** How variants in the non-coding DNA at the start of a gene can affect an organism's phenotype by affecting how well RNA polymerase binds to the DNA and therefore how much protein is produced.

Exam-style Questions

1 A farmer selects a male pig and a female pig and breeds them together. **Figure 1** shows the process.

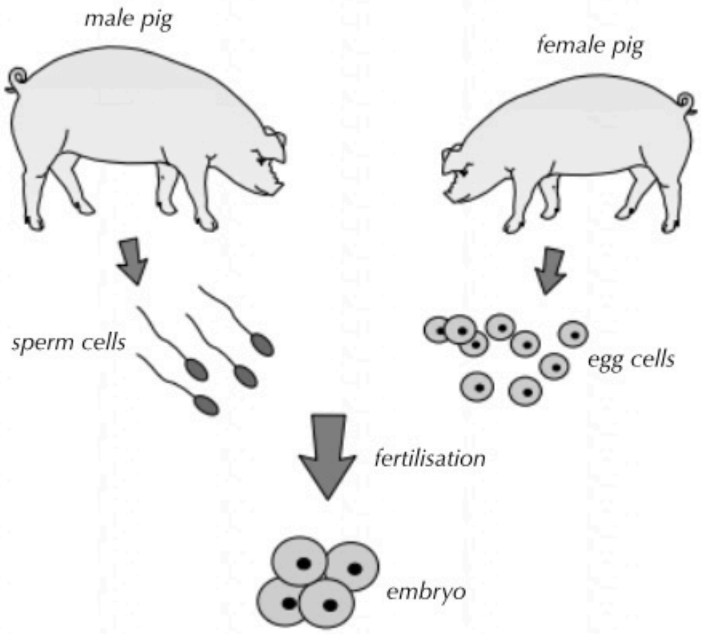


Figure 1

(a) Is the reproduction shown in **Figure 1** an example of sexual or asexual reproduction? Give a reason for your answer.

(1 mark)

(b) Outline **one** advantage of the type of reproduction shown in **Figure 1**.

(4 marks)

(c) The pigs that are born as a result of this process will share characteristics with both the male pig and the female pig. Explain why.

(2 marks)

(d) The sperm cells are gametes.
Explain why it is important that the sperm cells only have one set of chromosomes.

(1 mark)

(e) What type of cell division occurs in the embryo in order for it to grow?

(1 mark)

2 A scientist analyses a sample of DNA.

(a) There are 2.16×10^6 base pairs in the sample.
46% of the base pairs contain adenine (A).

Calculate the number of base pairs that contain cytosine (C).

(2 marks)

(b) Apart from bases, state **two** components of the DNA sample.

(2 marks)

(c) The scientist obtained the DNA sample from some cells. Suggest how the scientist could have precipitated the DNA out of a solution containing cell debris.

(1 mark)

3 **Figure 2** shows the amino acids coded for by a short sequence of mRNA.

arginine—histidine—glycine—proline

Figure 2

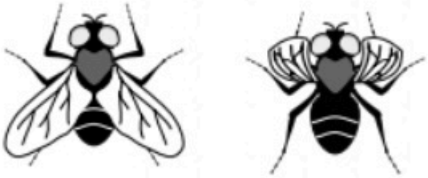
(a) State how many mRNA bases code for this amino acid sequence.

(1 mark)

(b) Describe how this amino acid sequence could be produced from the mRNA in a cell.

(4 marks)

4 Scientists often carry out genetic experiments on fruit flies. **Figure 3** shows a normal fruit fly and a fruit fly with a genetic variant that produces curly wings.



Normal fly

Fly with curly wings variant

Figure 3

Suggest an explanation for how a genetic variant in the coding DNA could lead to the curly wings phenotype shown in **Figure 3**, rather than the normal phenotype.

(4 marks)

1. Genes and Alleles

This page is all about how our genes determine our characteristics...

Learning Objectives:
- Know that most phenotypic features are the result of multiple genes rather than single gene inheritance.
- Be able to explain why there are differences in inherited characteristics as a result of alleles.
- Be able to explain the terms: gene, allele, dominant, recessive, homozygous, heterozygous, genotype and phenotype.

Specification References
3.12, 3.13, 3.19

Genes and characteristics

You might remember from page 89 that a gene is a section of DNA that codes for a specific protein. The genes you inherit control what characteristics you develop. Different genes control different characteristics and most characteristics are controlled by multiple genes interacting. However, some characteristics are controlled by a single gene — for example, red-green colour blindness in humans and round vs wrinkly peas (see next page).

What are alleles?

All genes exist in different versions called alleles. Gametes (see p.84) only have one allele, but all the other cells in an organism have two — one on each chromosome in a pair (see Figure 1). This is because we inherit half of our alleles from our mother and half from our father. In genetic diagrams (see pages 102-105), letters are usually used to represent alleles.

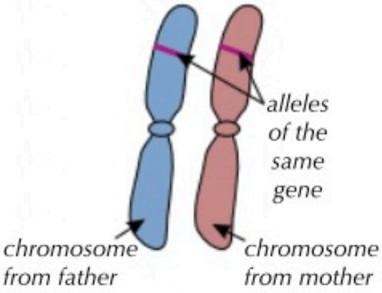


Figure 1: *Diagram showing two alleles for the same gene.*

For characteristics controlled by a single gene, if an organism has two alleles for that particular gene that are the same, then it's **homozygous** for that trait. If its two alleles for a particular gene are different, then it's **heterozygous**. If the two alleles are different, only one can determine what characteristic is present. The allele for the characteristic that's shown is called the **dominant** allele (use a capital letter for dominant alleles — e.g. 'C'). The other one is called **recessive** (and you show these with small letters — e.g. 'c').

For an organism to display a recessive characteristic, both its alleles must be recessive (e.g. cc). But to display a dominant characteristic the organism can be either CC or Cc, because the dominant allele overrules the recessive one if the plant/animal/other organism is heterozygous.

Your **genotype** is the combination of alleles you have, e.g. CC, cc or Cc. Your alleles work at a molecular level (by coding for slightly different proteins — see pages 93-94) to determine what characteristics you have — your **phenotype**, e.g. brown eyes, blonde hair, etc.

Practice Question — Fact Recall

Q1 Explain what is meant by each of these terms:

a) alleles b) homozygous c) dominant allele d) phenotype

2. Genetic Diagrams and Family Pedigrees

Learning Objectives:

- Be able to explain monohybrid inheritance using genetic diagrams, Punnett squares and family pedigrees.
- Be able to calculate and analyse outcomes (using probabilities, ratios and percentages) from monohybrid crosses and pedigree analysis for dominant and recessive traits.

Specification References
3.14, 3.16

The diagrams on the next few pages show how we inherit our characteristics...

Monohybrid inheritance

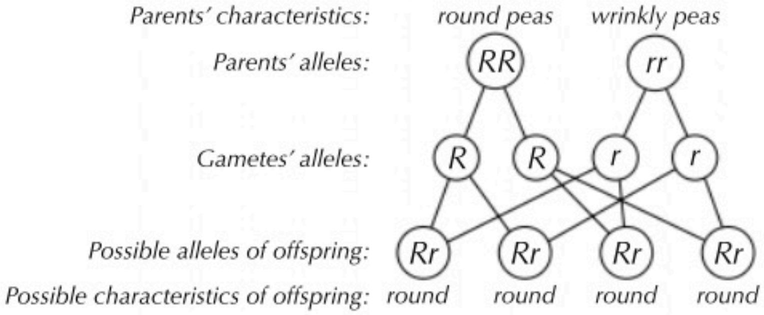
Characteristics that are determined by a single gene can be studied using **monohybrid crosses**. This is where you cross two parents to look at just one characteristic. In the exam they could ask you about the inheritance of any characteristic controlled by a single gene, as the principle's always the same.

Genetic diagrams of monohybrid inheritance

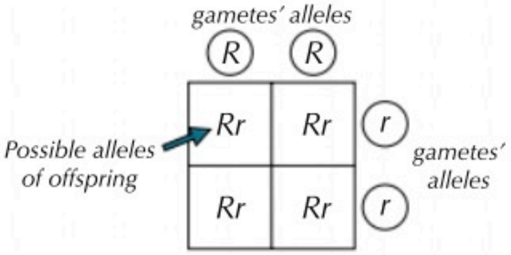
Genetic diagrams allow you to see how certain characteristics are inherited. The inheritance of round or wrinkly peas from pea plants is an example of monohybrid inheritance and can be shown using genetic diagrams.

Example 1

The gene which causes wrinkly peas is recessive, so you can use a small 'r' to represent it. Round peas are due to a dominant gene, which you can represent with a capital 'R'. If you cross one pea plant which produces wrinkly peas (rr) and one that produces round peas (in this case RR), all of the offspring will produce round peas — but they'll have the alleles Rr.


Parents' characteristics:
round peas
wrinkly peas
Parents' alleles:
RR
rr
Gametes' alleles:
R
R
r
r
Possible alleles of offspring:
Rr
Rr
Rr
Rr
Possible characteristics of offspring:
round
round
round
round

You can also show this genetic cross in a Punnett square:


gametes' alleles
Possible alleles of offspring
gametes' alleles

	R	R
r	Rr	Rr
r	Rr	Rr

You need to be able to use genetic diagrams to predict and explain the outcomes of monohybrid crosses between individuals for lots of different combinations of alleles. The outcomes are given as ratios and can be used to work out the probability of having offspring with a certain characteristic.

Tip: Monohybrid inheritance is also known as single gene inheritance.

Tip: 'Cross' just means 'breed together'.

***Figure 1:** The peas produced by pea plants can either be wrinkly (left) or round (right).*

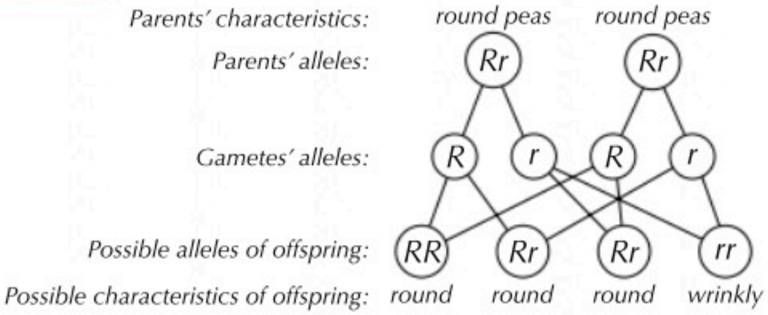
Tip: In this example, a plant producing wrinkly peas must be homozygous recessive (it must have 'rr' alleles). However, a plant producing round peas could be homozygous dominant or heterozygous — it can have two possible combinations of alleles — RR or Rr.

Probability is a measure of how likely something is to happen. In maths, the probability of a certain event happening is written as a number between 0 (impossible) and 1 (certain). It can also be written as a fraction or a percentage.

A 3:1 ratio in the offspring

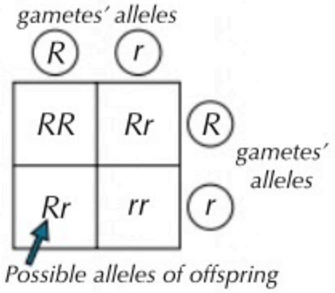
A cross could produce a 3:1 ratio for a certain characteristic in the offspring. The following example shows that this would happen if two of the heterozygous offspring from Example 1 were crossed.

Example 2


Parents' characteristics:
round peas
round peas
Parents' alleles:
Rr
Rr
Gametes' alleles:
R
r
R
r
Possible alleles of offspring:
RR
Rr
Rr
rr
Possible characteristics of offspring:
round
round
round
wrinkly

Again, this cross can be shown in a Punnett square:

This cross gives a 3:1 ratio of plants producing round peas to plants producing wrinkly peas. This means there's a 1 in 4, 25%, 0.25 or ¼ chance of any new pea plant having wrinkly peas. Remember that "results" like this are only probabilities — they don't say definitely what'll happen.


gametes' alleles

	R	*r*
R	*RR*	*Rr*
r	*Rr*	*rr*

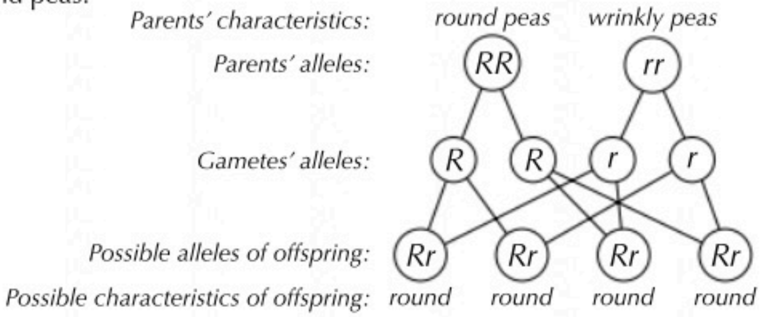
gametes' alleles
Possible alleles of offspring

All the offspring are the same

More than one cross could result in all of the offspring showing the same characteristic. Here you have to do some detective work to find out what's gone on:

Example 3

If you cross a homozygous pea plant that produces round peas (so has two dominant alleles — RR), with a homozygous pea plant that produces wrinkly peas (rr), all the offspring will be heterozygous (Rr), so produce round peas:


Parents' characteristics:
round peas
wrinkly peas
Parents' alleles:
RR
rr
Gametes' alleles:
R
R
r
r
Possible alleles of offspring:
Rr
Rr
Rr
Rr
Possible characteristics of offspring:
round
round
round
round

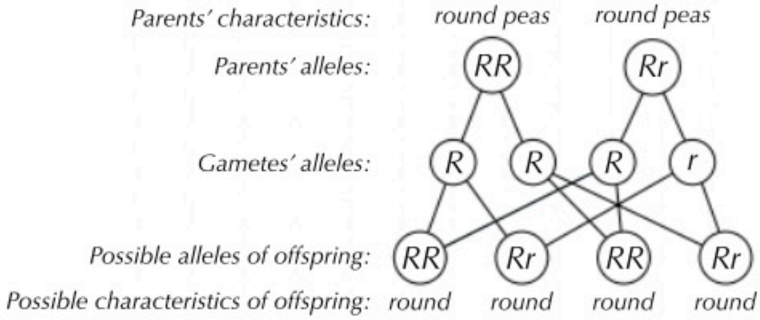
Tip: The 3:1 ratio of round to wrinkly peas shows that the round allele is dominant.

Exam Tip
A 3:1 ratio of plants producing round peas to plants producing wrinkly peas means there's a 1 in 4 chance of a new plant having wrinkly peas, not a 1 in 3 chance — it's an easy mistake to make, so be careful when you're talking about proportions and probabilities.

Tip: You can see this cross — and a Punnett square that shows the same thing — in Example 1 on the previous page.

So, there's a 100% probability of any new pea plant having round peas.

But, if you crossed a homozygous pea plant that produces round peas (RR), with a heterozygous pea plant that produces round peas (so has a dominant and a recessive allele — Rr), you would also only get offspring that produce round peas:


Parents' characteristics:
round peas
round peas
Parents' alleles:
RR
Rr
Gametes' alleles:
R
R
R
r
Possible alleles of offspring:
RR
Rr
RR
Rr
Possible characteristics of offspring:
round
round
round
round

To find out which cross you'd done, you'd have to breed the offspring together and see what kind of ratio you got — then you'd have a good idea. If it was a 3:1 ratio of round to wrinkly in the offspring, it's likely that you originally had RR and rr plants (see Example 2 on the previous page).

Tip: You know the drill by now — here's the Punnett square showing this cross:

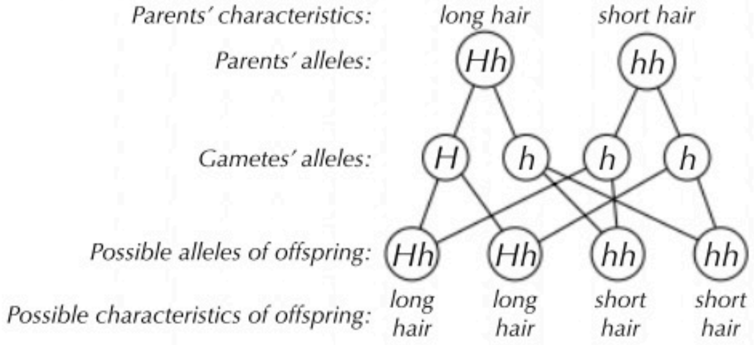
	R	R
R	RR	RR
r	Rr	Rr

A 1:1 ratio in the offspring

Next up is an example of when a cross produces a 1:1 ratio in the offspring — half the offspring are likely to show one characteristic and half are likely to show another characteristic. This time we're using cats with long and short hair. (Peas are a bit dull...)

Example 4

A cat's long hair is caused by a dominant allele 'H'. Short hair is caused by a recessive allele 'h'. A heterozygous cat with long hair (Hh) was bred with a homozygous cat with short hair (hh):


Parents' characteristics:
long hair
short hair
Parents' alleles:
Hh
hh
Gametes' alleles:
H
h
h
h
Possible alleles of offspring:
Hh
Hh
hh
hh
Possible characteristics of offspring:
long hair
long hair
short hair
short hair

Here's the Punnett square for this cross:

gametes' alleles

	H	h
h	Hh	hh
h	Hh	hh

Possible alleles of offspring

gametes' alleles

This is a 1:1 ratio, which gives a 50% probability of a new cat being born to these parents having long hair.

Exam Tip
Half the offspring of this cross are homozygous recessive — their genotype is 'hh', which produces a short-haired phenotype. The other half are heterozygous — their genotype is 'Hh', producing a long-haired phenotype. Get used to using terms such as 'homozygous', 'heterozygous', 'dominant', 'recessive' 'genotype' and 'phenotype' now — you need to know them for the exams.

Constructing genetic diagrams

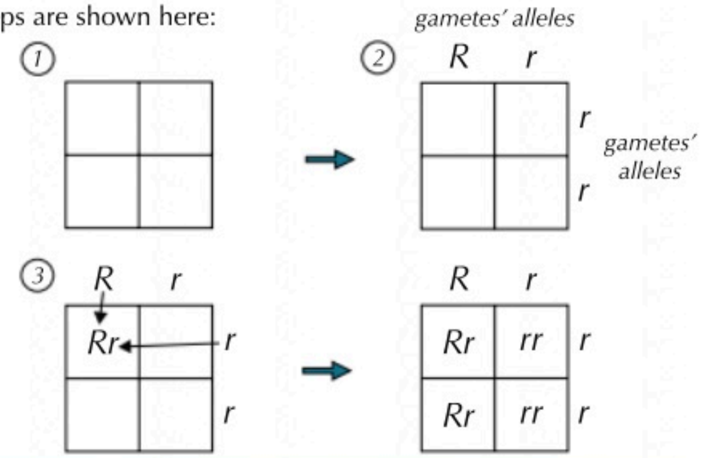
You need to be able to construct genetic diagrams for monohybrid crosses.

Example 1

Drawing a Punnett square to show a cross between a pea plant with round peas (Rr) and a pea plant with wrinkly peas (rr).

1. First, draw a grid with four squares.
2. Put the possible alleles from one parent down the side, and those from the other parent along the top.
3. Then in each middle square you fill in the letters from the top and side that line up with that square — the pairs of letters in the middle show the possible combinations of the alleles.

The steps are shown here:



gametes' alleles
1
2
R
r
r
r
gametes' alleles
3
R
r
Rr
r
r
R
r
Rr
rr
r
Rr
rr
r

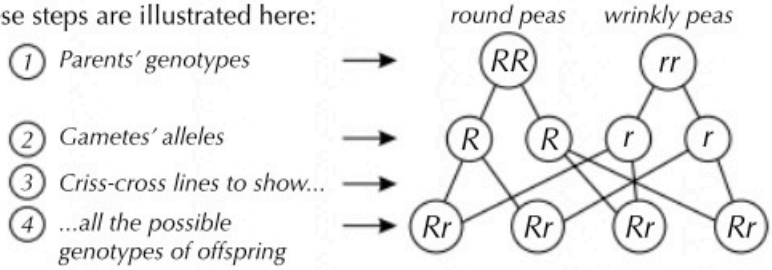
Exam Tip
If you're asked to produce a genetic diagram in the exam, you should be told what letters to use to represent the alleles.

Example 2

Drawing a genetic diagram to show a cross between a pea plant with wrinkly peas (rr) and a pea plant with round peas (RR).

1. Draw two circles at the top of the diagram to represent the parents. Put the round genotype in one and the wrinkly genotype in the other.
2. Draw two circles below each of the parent circles to represent the possible gametes. Put a single allele from each parent in each circle.
3. One gamete from the female combines with one gamete from the male during fertilisation, so draw criss-cross lines to show all the possible ways the alleles could combine.
4. Then write the possible combinations of alleles in the offspring in the bottom circles.

These steps are illustrated here:



round peas
wrinkly peas
1 Parents' genotypes
RR
rr
2 Gametes' alleles
R
R
r
r
3 Criss-cross lines to show...
4 ...all the possible genotypes of offspring
Rr
Rr
Rr
Rr

Exam Tip
You could be given any gene in a question about monohybrid inheritance. Whether the gene codes for a disease or a physical trait, you always draw and interpret the genetic diagrams in the same way.

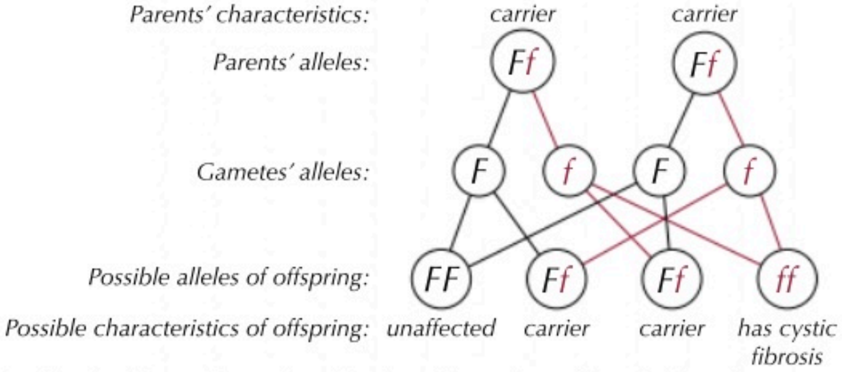
Family pedigrees

In genetics, a family pedigree is a diagram that shows how a characteristic (or disorder) is inherited in a group of related people. You might be asked to interpret one in the exam.

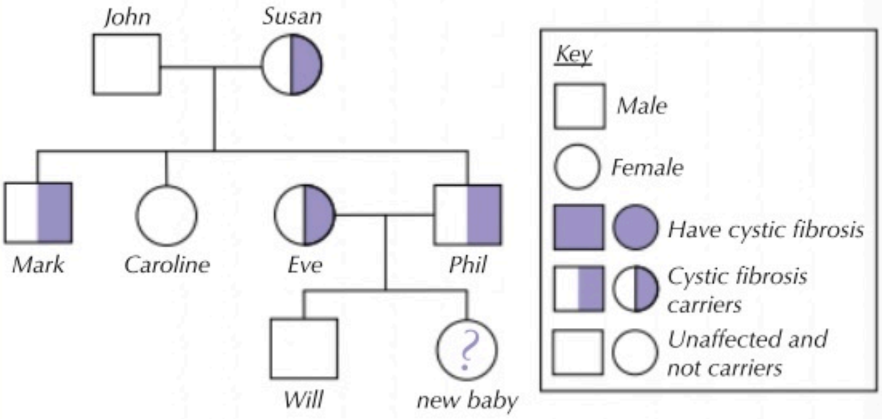
Example

Cystic fibrosis is an inherited disorder of the cell membranes. The allele which causes cystic fibrosis is a recessive allele, carried by about 1 person in 30. Because it's recessive, people with only one copy of the allele won't have the disorder — they're known as **carriers** (they carry the faulty allele, but don't have any symptoms).

For a child to inherit the disorder, both parents must be either carriers or have the disorder themselves. There's a 1 in 4 chance of a child having the disorder if both parents are carriers. This is shown in the diagram below, where 'f' is used for the recessive cystic fibrosis allele.


Parents' characteristics:
carrier
carrier
Parents' alleles:
Ff
Ff
Gametes' alleles:
F
f
F
f
Possible alleles of offspring:
FF
Ff
Ff
ff
Possible characteristics of offspring:
unaffected
carrier
carrier
has cystic fibrosis

Here is a family pedigree for a family with carriers of cystic fibrosis:


John
Susan
Mark
Caroline
Eve
Phil
Will
?
new baby
Key
Male
Female
Have cystic fibrosis
Cystic fibrosis carriers
Unaffected and not carriers

Tip: On this pedigree you can see that John and Susan are parents to Mark, Caroline and Phil. John and Susan are linked to their children by vertical lines. Eve and Phil are parents to Will and the new baby.

From the family pedigree, you can tell that:

1. The allele for cystic fibrosis isn't dominant because plenty of the family carry the allele but don't have the disorder.
2. There is a 25% chance that Eve and Phil's new baby will have the disorder and a 50% chance that it will be a carrier, as Eve and Phil are carriers but are unaffected.

The case of the new baby is just the same as in the genetic diagram above — the baby could be unaffected (FF), a carrier (Ff) or have cystic fibrosis (ff).

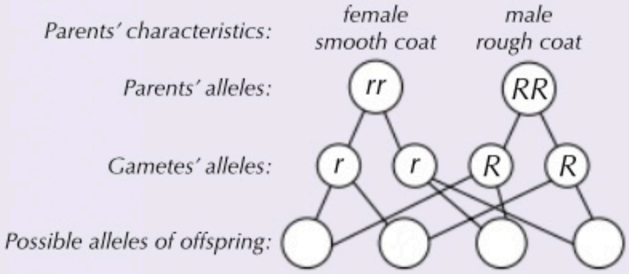
Exam Tip
A good way to work out a family pedigree is to write the genotype of each person onto it.

The probability of each outcome can also be expressed as a ratio — 1 : 2 : 1 for unaffected : carrier : disorder.

Exam Tip
Sometimes you can't tell a person's genotype from looking straight at the family pedigree and the key — you might need to do a bit of detective work and figure out the genotypes of other people first.

Practice Questions — Application

Q1 Charlotte has some guinea pigs with rough coats and some guinea pigs with smooth coats. The allele for a rough coat is represented by 'R'. The allele for a smooth coat is represented by 'r'. The rough coat allele is dominant to the smooth coat allele. She crosses a rough coated guinea pig (RR) with a smooth coated guinea pig (rr). Here is an incomplete genetic diagram of the cross:

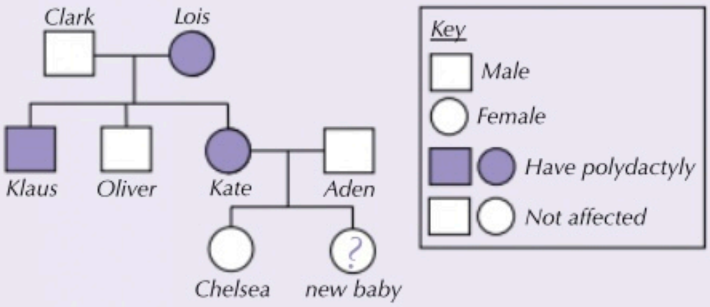

Parents' characteristics:
female smooth coat
male rough coat
Parents' alleles:
rr
RR
Gametes' alleles:
r
r
R
R
Possible alleles of offspring:

a) Complete the diagram to show the possible alleles of the offspring.

b) What type of coat will the offspring have?

Q2 The family pedigree below shows the inheritance of the inherited disorder polydactyly in a family.

Tip: Polydactyly is an inherited disorder that results in a person being born with extra fingers or toes.


Clark
Lois
Klaus
Oliver
Kate
Aden
Chelsea
?
new baby
Key
Male
Female
Have polydactyly
Not affected

Using the family pedigree, answer the following questions:

a) The allele for polydactyly is dominant.
How can you tell this from the family pedigree?

b) If the new baby was a girl with polydactyly, what symbol would she have on the family pedigree?

For the following questions, use 'D' to represent the allele for polydactyly and 'd' to represent the allele for an unaffected person.

c) Give the genotype of the following individuals:

i) Clark ii) Kate

d) Kate and Aden are having a baby. Draw a Punnett square to show the inheritance of polydactyly from Kate and Aden.
What is the probability the new baby will have polydactyly?

Learning Objective:

- Be able to describe the work of Mendel in discovering the basis of genetics and recognise the difficulties of understanding inheritance before the mechanism was discovered.

Specification Reference 3.11B

3. The Work of Mendel

We haven't always known as much about genetics and inheritance as we do now. The work of a monk called Gregor Mendel helped us on our way...

Who was Gregor Mendel?

Gregor Mendel was an Austrian monk who trained in mathematics and natural history at the University of Vienna. On his garden plot at the monastery, Mendel noted how characteristics in plants were passed on from one generation to the next. The results of his research were published in 1866 and eventually became the foundation of modern genetics.

Mendel's work

Mendel did lots of experiments with pea plants. In one experiment he crossed two pea plants of different heights — a tall pea plant and a dwarf pea plant. The offspring produced were all tall pea plants (see Figure 2).

Figure 1: *Gregor Mendel.*

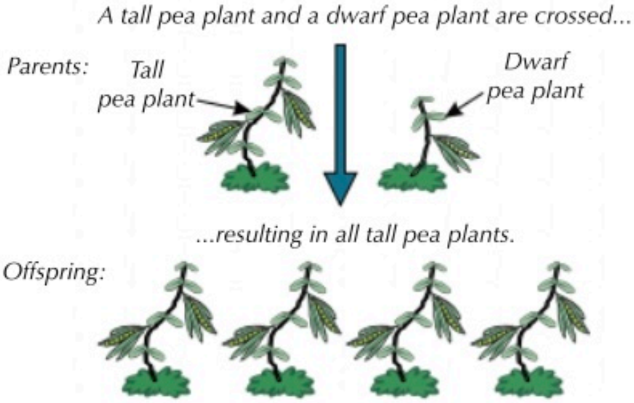

A tall pea plant and a dwarf pea plant are crossed...
Parents:
Tall pea plant
Dwarf pea plant
...resulting in all tall pea plants.
Offspring:

Figure 2: *Diagram of the first cross in Mendel's pea plant height experiment.*

He then bred two of these tall pea plants together. The resulting offspring consisted of three tall pea plants and one dwarf pea plant (see Figure 3).

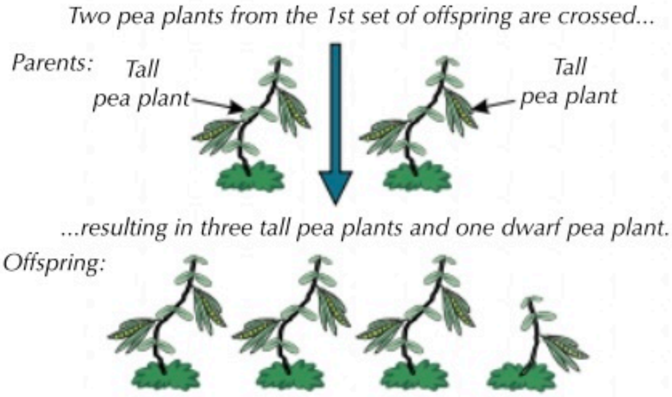

Two pea plants from the 1st set of offspring are crossed...
Parents:
Tall pea plant
Tall pea plant
...resulting in three tall pea plants and one dwarf pea plant.
Offspring:

Figure 3: *Diagram of the second cross in Mendel's pea plant height experiment.*

Explaining Mendel's results

From his pea plant height experiment, Mendel had shown that the height characteristic in pea plants was determined by separately inherited "hereditary units" passed on from each parent.

This can be explained using genetic diagrams, where **T** represents the hereditary unit for tall plants and **t** represents the hereditary unit for dwarf plants.

First cross

As shown in Figure 4, in the first of Mendel's crosses, a tall and a dwarf pea plant are crossed together.

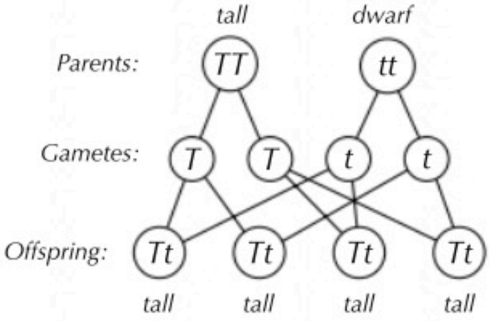


Figure 4: *Genetic diagram of the first cross in Mendel's pea plant height experiment.*

The resulting offspring are **Tt** — they are all tall plants, but they all carry the hereditary unit for dwarf plants.

Second cross

In the second cross, two tall pea plants from the first cross are crossed together (see Figure 5).

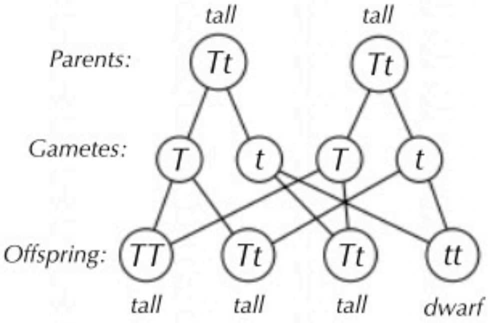


Figure 5: *Genetic diagram of the second cross in Mendel's pea plant height experiment.*

The resulting offspring are **TT**, **Tt**, **Tt** and **tt** — this gives three tall plants and one dwarf plant.

The ratios of tall and dwarf plants in the offspring show that the hereditary unit for tall plants, **T**, is dominant over the hereditary unit for dwarf plants, **t**, i.e. plants with hereditary units for both types of plant (**Tt**) will be tall plants.

Exam Tip
In Mendel's pea plant experiments he also investigated lots of other pea plant characteristics, such as flower colour:

So don't be put off if you have a question in the exam about one of Mendel's other experiments — just use what you've learnt here to answer the question.

Tip: Figure 5 shows that when two tall (Tt) pea plants are crossed, there's a 3:1 ratio of tall:dwarf pea plants in the offspring, or a 25% chance of getting a dwarf plant from this cross. There's more about ratios on p.325 and more about probabilities on p.103.

Tip: We now know that the pea plants in the first cross were each homozygous for their trait and that their tall offspring were heterozygous — see p.101 for more.

Mendel's conclusions

Tip: Although Mendel didn't perform experiments on animals, similar experiments have since shown that heredity in animals works the same way.

From all his experiments on pea plants, Mendel reached these three important conclusions about heredity in plants:

1. Characteristics in plants are determined by "hereditary units".
2. Hereditary units are passed on to offspring unchanged from both parents, one unit from each parent.
3. Hereditary units can be dominant or recessive — if an individual has both the dominant and the recessive unit for a characteristic, the dominant characteristic will be expressed.

The importance of Mendel's work

Tip: The idea that genes are the units of inheritance is called 'gene theory'.

We now know that the "hereditary units" are of course genes. But Mendel's work was cutting edge and new to the scientists of the day. They didn't have the background knowledge to properly understand his findings — they had no idea about genes, DNA and chromosomes.

It wasn't until after his death that people realised how significant his work was and that the mechanism of inheritance could be fully explained.

Practice Questions — Fact Recall

Q1 True or false? One of the conclusions that Mendel reached from his experiments was that hereditary units are changed before being passed on from parents to offspring.

Q2 Why didn't Mendel get any credit for his work while he was alive?

Exam Tip
Mendel is one of the great scientists, who found out really important things about genetics. In the exam don't get him mixed up with other great scientists, like Darwin.

Practice Question — Application

Q1 Mendel did experiments on pea plants with different seed colours. From these experiments he found that there is a hereditary unit in pea plants that gives them green seeds and one that gives them yellow seeds. The hereditary unit for yellow pea seeds is dominant.

Tick or cross the boxes in the table to show which hereditary units pea plants with the following seed colours could have. (You can tick more than one option for each seed colour.)

Seed colour of pea plant	Type of hereditary unit		
	Just green	Just yellow	Both green and yellow
Green			
Yellow			

4. Sex Determination and Sex-linked Disorders

Our sex is determined by two chromosomes, X and Y. As with our other chromosomes, these two can carry faulty alleles that result in genetic disorders.

Learning Objectives:

- Be able to describe how the sex of offspring is determined at fertilisation, using genetic diagrams.
- H Be able to explain how sex-linked genetic disorders are inherited.

Specification References
3.15, 3.18B

Sex chromosomes

There are 23 pairs of chromosomes in every human body cell. Of these, 22 are matched pairs of chromosomes — these just control your characteristics. The 23rd pair are labelled XY or XX. They're the two chromosomes that decide your sex — whether you turn out male or female.

Males have an **X** and a **Y** chromosome: **XY**
The Y chromosome causes male characteristics.

Females have **two X** chromosomes: **XX**
The XX combination allows female characteristics to develop.

Gametes are haploid (see p.27) so they only contain one sex chromosome. All eggs have one X chromosome, but a sperm can have either an X chromosome or a Y chromosome.

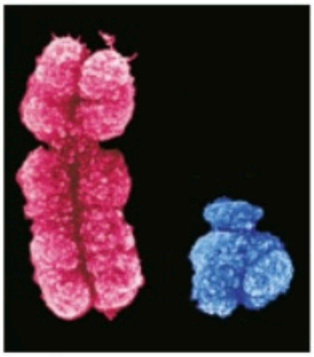


Figure 1: *The X and Y chromosomes. The Y chromosome is smaller.*

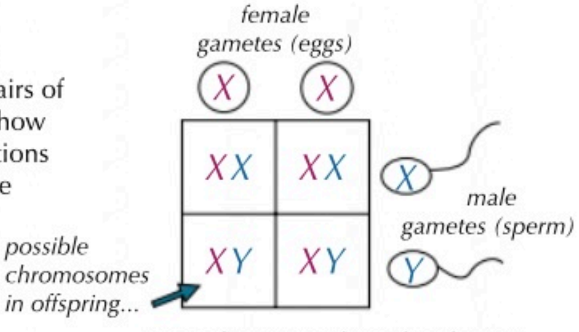
Sex determination and genetic diagrams

At fertilisation, the sperm fertilises the egg, and the chromosomes from the gametes combine, forming a new individual with the correct number of chromosomes (see page 84). Whether the individual is male or female depends on whether the sperm that fertilises an egg carries an X or a Y chromosome — this is sex determination.

Sex determination can be shown using genetic diagrams like the ones you saw on pages 102-105. These diagrams show the inheritance of chromosomes not alleles, but they work in the same way.

Example

The Punnett square in Figure 2 shows sex determination. The pairs of letters in the middle show the possible combinations of chromosomes in the offspring.



...two males (XY) and two females (XX).

Figure 2: *Punnett square showing sex determination.*

Tip: You can construct genetic diagrams to show sex determination in the same way as for monohybrid inheritance (see p.105). Just put the possible chromosomes from each gamete where you would normally put the alleles from each gamete. Then fill in the possible combinations of the offspring — XX or XY.

Tip: Remember, one gamete from the female combines with one gamete from the male during fertilisation. It's quite easy to get confused, so check you aren't drawing lines that put both the male's gametes or both the female's gametes into the same circle.

Tip: Only one of these possible combinations would actually happen for any one offspring.

Figure 3 is another type of genetic diagram showing sex determination. The possible chromosomes in the offspring are shown in the bottom circles.

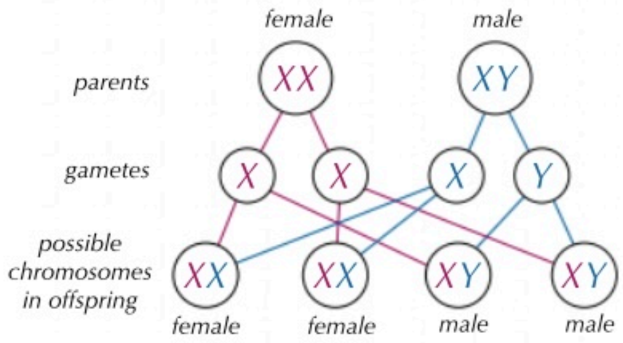

female
male
parents
XX
XY
gametes
X
X
X
Y
possible chromosomes in offspring
XX
XX
XY
XY
female
female
male
male

Figure 3: *Genetic diagram showing sex determination.*

Both Figure 2 and Figure 3 show two XX results and two XY results, so there's an equal probability of getting a boy or a girl. This can be written as a 50:50 ratio, which is the same as 1:1. Alternatively, you could say the probability of getting a boy is 1 in 2, 50%, 0.5 or ½.

Don't forget that this 50:50 ratio is only a probability at each pregnancy. If you had four children, they could all be boys.

Sex-linked genetic disorders Higher

A characteristic is sex-linked if the allele that codes for it is located on a sex chromosome (X or Y).

The Y chromosome is smaller than the X chromosome and carries fewer genes. So most genes on the sex chromosomes are only carried on the X chromosome. As men only have one X chromosome they often only have one allele for sex-linked genes (see Figure 4).

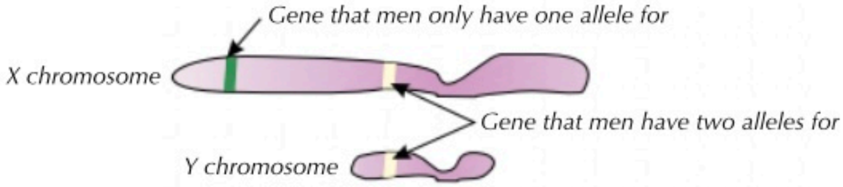

Gene that men only have one allele for
X chromosome
Gene that men have two alleles for
Y chromosome

Figure 4: *Diagram showing the difference in genes present on sex chromosomes.*

Tip: H Disorders caused by alleles on the X chromosome are also called X-linked disorders.

Because men only have one allele, the characteristic of this allele is shown even if it is recessive. This makes men more likely than women to show recessive characteristics for genes that are sex-linked.

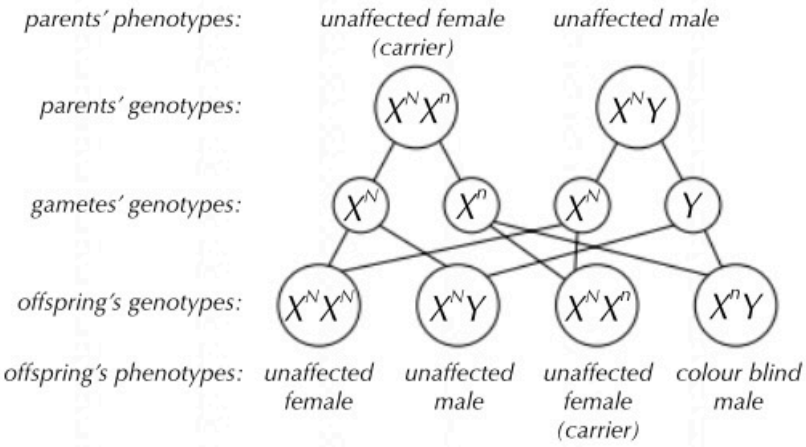
Disorders caused by faulty alleles located on sex chromosomes are called sex-linked genetic disorders.

Example 1 **Higher**

Colour blindness is caused by a faulty recessive allele carried on the X chromosome. Women need two copies of the recessive allele to be colour blind, while men only need one copy. This means colour blindness is much rarer in women than men. A woman with only one copy of the recessive allele is a carrier of colour blindness. This means that she isn't colour blind herself, but she can pass the allele on to her offspring.

The inheritance of colour blindness can be shown in a genetic diagram. As it's sex-linked, both the chromosome and the allele are written in the genetic diagram, e.g. as X^n, where X represents the X chromosome and n the faulty allele for colour vision. The Y chromosome doesn't have an allele for colour vision so is just represented by Y.

Here's a genetic cross between a carrier female and an unaffected (non-colour blind) male:



Key: N = normal colour vision allele n = faulty colour vision allele

Figure 5: *Genetic diagram showing the inheritance of the allele that causes colour blindness.*

In Figure 5, the ratio of unaffected : colour blind offspring is 3 : 1. Be careful with this one, it may be disguised as a 2 : 1 : 1 ratio (unaffected : carrier : colour blind), but it means the same thing.

In other words, there's a 1 in 4 (25%) chance of a child being colour blind. This rises to 1 in 2 (50%) if you know that the child will be a boy.

Example 2 **Higher**

Haemophilia is another sex-linked disorder. It is a disease where the blood doesn't clot properly. It's also caused by a faulty allele carried on the X chromosome, so it's inherited in the same way as colour blindness.

A genetic diagram showing a cross between an unaffected female carrier of haemophilia and an unaffected male will look the same as the one in Figure 5.

Tip: **H** Males can't be carriers of colour blindness — they only have one X chromosome so they will always show the characteristic of the allele.

Tip: **H** A female with colour blindness would have the genotype X^nX^n. For a female to inherit colour blindness, her father must be colour blind. Her mother must also either be a carrier (giving a 50% chance that she will inherit the disorder) or also be colour blind (100% chance of inheritance).

Tip: **H** A male with colour blindness can't pass the condition to his son because males don't inherit their X chromosome from their father.

Tip: **H** Sex-linked disorders can also be caused by a dominant allele on the X chromosome. This means that if a faulty dominant allele is passed on to the offspring, the offspring will have a 100% chance of developing the disorder.

Practice Questions — Fact Recall

Q1 How many of the 23 pairs of human chromosomes determine sex?

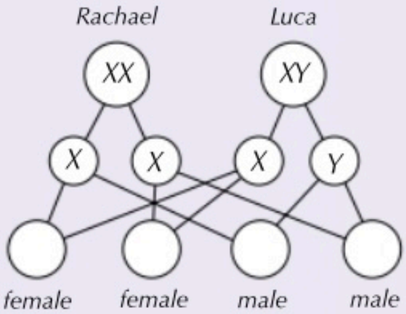
Q2 True or False? All sperm cells carry the Y chromosome.

Q3 Why are recessive sex-linked disorders more rare in women than in men?

Practice Questions — Application

Rachael and her husband Luca are expecting their first child.

The incomplete genetic diagram below shows sex inheritance.



Q1 Copy and complete the genetic diagram above to show the possible combinations of sex chromosomes that the baby could have.

Q2 What is the probability that their child will be a boy?

Q3 Draw a Punnett square to show the possible combinations of sex chromosomes that Rachael and Luca's baby could have.

Q4 Haemophilia is caused by a faulty recessive allele on the X chromosome. Rachael is unaffected and not a carrier of the disease. Luca has haemophilia. Rachael and Luca have a son. Explain whether or not he will have haemophilia.

5. Inheritance of Blood Groups

Some genes have more than two different alleles. This results in more than two possible phenotypes. A good example of this are the alleles that determine blood group.

Learning Objective:

- Be able to describe the inheritance of the ABO blood groups with reference to codominance and multiple alleles.

Specification Reference 3.17B

Multiple alleles

So far you've probably only come across cases where there are two possible alleles for a gene — one that's recessive and one that's dominant. Well, sometimes you'll get more than two (multiple) alleles for a single gene. This makes studying the inheritance of characteristics controlled by these genes a little more complicated.

For example, humans have four potential blood types — O, A, B and AB. The gene for blood type in humans has three different alleles — I^O, I^A and I^B. Each allele determines what type of antigen is present on the outside of the red blood cells. I^A results in A antigens on the red blood cell surface, I^B results in B antigens and I^O results in no antigens.

Tip: Antigens are molecules that can cause an immune response (see p.165). The antigens found on red blood cells are sugars.

The alleles, I^A and I^B, are **codominant** with each other.

Codominance is when two alleles of a gene are expressed in the same phenotype.

This means that when an individual has both the I^A and I^B alleles (genotype I^AI^B), then they'll have the blood type AB — one allele isn't dominant over the other one. However, I^O is recessive. So when you get I^O with, say, I^A (genotype I^AI^O) then you only see the effect of I^A — giving blood type A. You only get blood type O when you have two of the recessive alleles (I^OI^O) — this is summarised in Figure 1.

Tip: Type AB red blood cells have both A antigens and B antigens on their surface.

Genotype	Phenotype
I^AI^A or I^AI^O	Group A
I^BI^B or I^BI^O	Group B
I^AI^B	Group AB
I^OI^O	Group O

Figure 1: *Table showing possible genotypes and the corresponding phenotypes for the ABO blood groups.*

Tip: Recessive blood groups are normally really rare, but it just so happens that loads of people in Britain are descended from people who were I^OI^O, so O's really common.

Genetic diagrams for predicting blood groups

You can draw genetic diagrams for codominant alleles in the same way that you would for alleles that are recessive and dominant (see page 105). The tricky bit is predicting the potential phenotypes in the offspring once you've worked out what the potential genotypes are. You need to remember how the different alleles interact with each other to produce a phenotype.

Tip: Remember, even though some genes have multiple possible alleles, an individual will only ever have two alleles because they get one from each parent.

Example

- A man is blood group A. His genotype is I^AI^O. A woman is blood group B. Her genotype is I^BI^O. Figure 2 shows the alleles of the gametes that they can produce.
- The man and the woman have a child. The possible genotypes and phenotypes are shown in the Punnett square in Figure 2. As you can see from the diagram, the child could have any one of four different blood groups (AB, A, B or O).
- The child also has an equal chance (1 in 4 or 25%) of having each blood group.

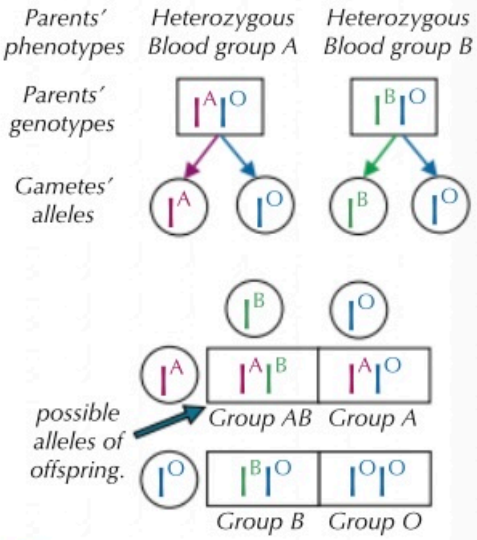

Parents' phenotypes
Heterozygous Blood group A
Heterozygous Blood group B
Parents' genotypes
I^AI^O
I^BI^O
Gametes' alleles
I^A
I^O
I^B
I^O
I^B
I^O
I^A
I^AI^B
Group AB
I^AI^O
Group A
possible alleles of offspring.
I^O
I^BI^O
Group B
I^OI^O
Group O

Figure 2: *Diagram showing blood group inheritance.*

Tip: Just like the Punnett square on p.105, the parents' gametes are written along the top and the sides of the square. They're combined in the middle to show the possible genotypes of the offspring.

Practice Questions — Fact Recall

Q1 What does it mean when a gene has multiple alleles?

Q2 What does it mean when alleles are codominant?

Q3 Give the allele for blood type which is recessive.

Practice Questions — Application

Q1 Lois has type B blood.
Which of the following options could show her genotype?

A I^AI^B

B I^OI^O

C I^BI^O

D I^AI^O

Q2 What is the probability of a person with the genotype I^AI^O passing on the I^A allele to their offspring?

6. Variation

These pages are all about the differences between you, me, and well... everyone else really. It's fascinating stuff...

Learning Objectives:

- Be able to describe the causes of variation that influence phenotype, including:
  - genetic variation — different characteristics as a result of mutation and sexual reproduction;
  - environmental variation — different characteristics caused by an organism's environment (acquired characteristics).
- Know that there is usually extensive genetic variation within a population of a species and that this arises through mutations.
- Know that most genetic mutations have no effect on the phenotype, some mutations have a small effect on the phenotype and, rarely, a single mutation will significantly affect the phenotype.

Specification References
3.20, 3.22, 3.23

What is variation?

Different species look... well... different — my dog definitely doesn't look like a daisy. But even organisms of the same species will usually look at least slightly different — e.g. in a room full of people you'll see different colour hair, individually shaped noses, a variety of heights, etc.

These differences are called the variation within a species — and there are two types of variation: **genetic variation** and **environmental variation**.

Genetic variation

Genetic variation within a species is caused by organisms having different alleles (versions of genes) which can lead to differences in phenotype (the characteristics an organism displays).

Genetic variation can be caused by new alleles arising through mutations (see next page). Sexual reproduction also causes genetic variation since it results in alleles being combined in lots of different ways in offspring (see page 85). Sexual reproduction means no two members of a species are genetically identical (apart from identical twins).

Some characteristics are determined only by genes.

Examples

- Flower colour in violets.
- Eye colour.
- Blood group.
- Inherited disorders (e.g. haemophilia or cystic fibrosis).

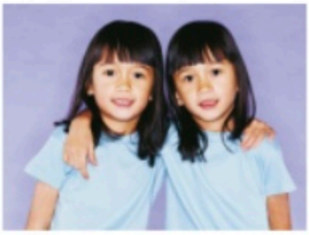


Figure 1: *Identical twins have exactly the same genes, which is why they look so alike.*

Environmental variation

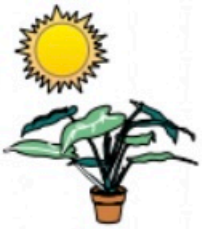
The environment that organisms live and grow in also causes differences between members of the same species — this is called environmental variation. Environmental variation covers a wide range of differences — from losing your toes in a piranha attack, to getting a suntan, to having yellow leaves and so on. Basically, any difference that has been caused by the conditions something lives in is an environmental variation.

Environmental variations in phenotype are also known as **acquired characteristics**. They're characteristics that organisms acquire (get) during their lifetimes.

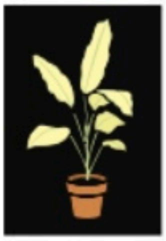
Tip: Plants are strongly influenced by environmental factors, e.g. sunlight, moisture level, temperature and soil mineral content.

Example

A plant grown on a nice sunny windowsill would grow luscious and green.



The same plant grown in darkness would grow tall and spindly and its leaves would turn yellow — these are acquired characteristics (environmental variations).



Genetic and environmental variation

Most characteristics are determined by a mixture of genetic and environmental factors.

Tip: Environmental factors aren't just the physical things around you. They can include things like the way you were brought up too.

Examples

- Height — the maximum height that an animal or plant could grow to is determined by its genes. But whether it actually grows that tall depends on its environment, e.g. how much food it gets.
- Intelligence — one theory is that although your maximum possible IQ might be determined by your genes, whether or not you get to it depends on your environment, e.g. your upbringing and school life.
- Health — some people are more likely to get certain diseases (such as cancer or heart disease) because of their genes. But lifestyle also affects the risk, e.g. whether you smoke or how much junk food you eat.

Mutations

Tip: There is more on DNA mutations on pages 93-94.

Occasionally a gene may mutate. A mutation is a random change in the base sequence of an organism's DNA.

Mutations mean that the gene is altered, which produces an allele, or a different version of the gene. As the gene codes for the sequence of amino acids that make up a protein, gene mutations sometimes lead to changes in the protein that it codes for.

Tip: Mutations in DNA happen at random — it doesn't matter whether or not they'll result in a beneficial change.

Most mutations have very little or no effect on the protein that the gene codes for. Some will change it to such a small extent that its function is unaffected. This means that most mutations have no effect on an organism's phenotype — they are neutral.

Tip: Alleles are also known as genetic variants.

Examples

- A mutation to a gene may produce an allele that codes for the same sequence of amino acids, so the same protein is produced.
- The mutation may cause a change in one amino acid in a protein, but the change has no effect on the protein's function.

There tends to be a lot of genetic variation within a population of a species. This is mostly due to neutral mutations.

Some mutations have a small influence on the organism's phenotype — they alter the individual's characteristics but only slightly.

Example

Some characteristics, e.g. eye colour, are controlled by more than one gene. A mutation in one of the genes may change the eye colour a bit, but the difference might not be huge.

Very occasionally, a mutation can have a dramatic effect on phenotype. This could be because it results in the production of a protein that is so different, it can no longer carry out its function.

Example

The genetic disorder, cystic fibrosis, is caused by a mutation that has a huge effect on phenotype. The gene codes for a protein that controls the movement of salt and water into and out of cells. However, the protein produced by the mutated gene doesn't work properly. This leads to the production of thick, sticky mucus in the lungs and digestive system, which can make it difficult to breathe and to digest food.

New combinations of alleles may also interact with each other to produce new phenotypes.

Tip: Mutations that result in a large change in phenotype are very rare.

Tip: If the environment changes, and the new phenotype makes an individual more suited to the new environment, it can become common throughout the species relatively quickly by natural selection (see p.125).

Practice Questions — Fact Recall

Q1 True or False? Only differences in genes can cause variation within a population.

Q2 a) What is a mutation?

b) Explain why most mutations have no effect on an organism's phenotype.

Practice Questions — Application

Q1 For the plant characteristics below, say whether they are determined by genes only, the environment only, or both.

a) stem height

b) spots caused by a fungus

Q2 Identical twins have exactly the same genes.
Non-identical twins don't. Studies have shown that:

- identical twins tend to have more similar IQs than non-identical twins (Study 1).
- identical twins who are brought up together tend to have more similar IQs than identical twins who are brought up separately (Study 2).

What do the results of Studies 1 and 2 suggest about the influence of genes and the environment on IQ? Explain your answer.

Learning Objective:

- Be able to discuss the outcomes of the Human Genome Project and its potential applications within medicine.

Specification Reference 3.21

Tip: A genome is the entire set of genetic material in an organism (see p.89).

7. The Human Genome Project

Scientist have worked hard to identify genes within our genome that contribute to disease. This was achieved through the Human Genome Project.

Mapping the human genome

Thousands of scientists from all over the world collaborated (worked together) on the Human Genome Project. The big idea was to find every single human gene. The project officially started in 1990 and a complete map of the human genome, including the locations of around 20 500 genes, was completed in 2003.

Now that the genes have all been found, scientists are trying to figure out what they all do. So far, the project has helped to identify about 1800 genes related to disease, which has huge potential benefits for medicine (see below).

Medical applications

Understanding the human genome is a really important tool for many branches of medicine.

Tip: Just because somebody has genes which make them susceptible to a disease, it does not mean that they will definitely develop it — they are just at a greater risk.

Prediction and prevention of disease

Many common diseases like cancers and heart disease are caused by the interaction of different genes, as well as lifestyle factors. If doctors knew what alleles predisposed people to what diseases, we could all get individually tailored advice on the best diet and lifestyle to avoid our likely problems. Doctors could also check us regularly to ensure early treatment if we do develop the diseases we're susceptible to. This could increase the chance of a full recovery.

Testing and treatment for inherited disorders

Inherited disorders (e.g. cystic fibrosis) are caused by the presence of one or more faulty alleles in a person's genome. Thanks to the Human Genome Project, scientists are now able to identify the genes and alleles that are suspected of causing an inherited disorder much more quickly than they could do in the past. Once an allele that causes an inherited disorder has been identified, people can be tested for it and it may be possible to develop better treatments or even (eventually) a cure for the disease.

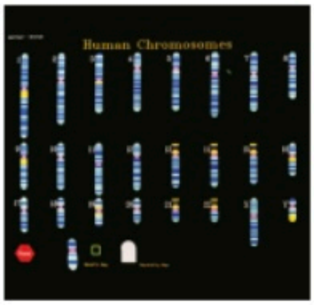


Figure 1: *Analysis of human chromosomes during the Human Genome Project.*

Example

Gene therapy is when a working copy of a gene is introduced into cells to treat a genetic disease. For example, research is being carried out to try to find a way to use gene therapy to treat cystic fibrosis patients.

New and better medicines

Some alleles affect how our individual bodies will react to certain diseases and to the possible treatments for them. Scientists can use this knowledge to design new drugs that are specifically tailored to people with a certain allele. They can also determine how well an existing drug will work for an individual.

Example

Some breast cancer drugs are only effective in women who have certain alleles. So patients can be tested to see whether or not they will respond to a particular drug.

Genetic tests can also help determine what dosage is most appropriate for particular drugs in different patients.

Example

Children with leukaemia may get a certain genetic test so that doctors can prescribe the correct dosage of medicine to prevent toxic side-effects.

Tip: More generally, knowing how a disease affects us on a molecular level should make it possible to design more effective treatments with fewer side-effects.

Ethical issues raised by genetic analysis

Despite the many advantages of the Human Genome Project, the genetic analysis it has enabled could have some drawbacks.

Examples

- If a person knows they have alleles which make them susceptible to a particular disease, it could lead to increased stress levels. E.g. someone who knows they are susceptible to a brain disease could panic every time they get a headache (even if they never go on to develop the disease).
- Someone who knows they carry a faulty allele could come under pressure not to have children (to prevent them potentially passing on that allele).
- Employers and insurers could also discriminate against those who have a genetic likelihood of a disease. This could result in difficulty finding employment or getting life insurance.

Practice Questions — Application

Sarah's mother has breast cancer caused by a harmful mutation in the *BRCA1* gene. A genetic test determines that Sarah has inherited the gene, putting her at increased risk of developing breast cancer.

Q1 Suggest one advantage of Sarah having this genetic test.

Q2 Suggest two disadvantages of Sarah having this genetic test.

Topic 3b Checklist — Make sure you know...

Genes and Alleles

☐ That most characteristics are controlled by several genes, but some are controlled by just one gene.

☐ That all genes exist in different forms called alleles, and that if an organism has two alleles for a gene that are the same then it is homozygous. If the two alleles are different then it's heterozygous.

☐ That if an individual is heterozygous for a characteristic, the allele for the characteristic that is displayed is dominant and the other allele is recessive. You need to be homozygous recessive for a recessive characteristic to be displayed.

cont...

☐ That your genotype is the combination of alleles you have and that these alleles work at the molecular level to determine your phenotype — the characteristics that you have.

Genetic Diagrams and Family Pedigrees

☐ That monohybrid inheritance is where the alleles of a single gene control a characteristic, and that this can be explained using genetic diagrams, Punnett squares and family pedigrees.

☐ How to express the results of monohybrid crosses and pedigree analysis using probabilities, ratios and percentages.

The Work of Mendel

☐ How Mendel's experiments with pea plants led him to develop the idea of "hereditary units".

☐ That what Mendel called "hereditary units" are what we now know as genes and that his work was not appreciated until after his death because people were not aware of things like genes, DNA and chromosomes at the time.

Sex Determination and Sex-linked Disorders

☐ That the 23rd pair of chromosomes are called sex chromosomes and how these determine sex.

☐ How to use genetic diagrams to describe sex determination.

☐ **H** How alleles causing some genetic disorders can be linked to the sex chromosomes and passed on to offspring.

Inheritance of Blood Groups

☐ That the gene determining ABO blood group has three possible alleles giving rise to four possible blood groups (A, B , AB and O), and that the alleles for type A blood (I^A) and type B blood (I^B) are codominant, while the allele for type O blood (I^O) is recessive.

☐ How to explain the inheritance of blood groups.

Variation

☐ That variation within a species is the differences between individuals, and that these differences are caused by genetic variation, environmental variation (acquired characteristics), or both.

☐ That there is usually a lot of genetic variation within a population of a species and that this arises through mutations in DNA and sexual reproduction.

☐ That most mutations have no effect on phenotype, some have a small effect on phenotype and a few have a big effect on phenotype.

The Human Genome Project

☐ That the work of the Human Genome Project has medical applications and what these might be.

Exam-style Questions

1 Huntington's disease is an example of an inherited disorder.
It is caused by a dominant faulty allele, which is represented by the letter 'H'.
The other allele for the gene is represented by the letter 'h'.

(a) Give the possible genotype(s) of a person with Huntington's disease.

(1 mark)

(b) A person is homozygous for the Huntington's disease allele.
Which of the following shows the person's genotype?

A HH

B hh

C Hh

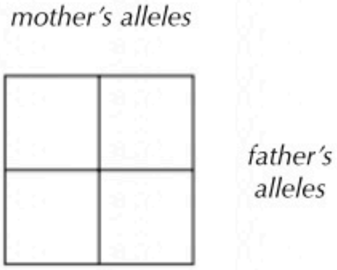
D H

(1 mark)

(c) The person's parents are both heterozygous for the Huntington's disease allele.

Complete the Punnett square below to show the probability of any offspring of these two heterozygous individuals inheriting Huntington's disease.

Give the probability as a percentage.



(2 marks)

2 Kevin and Roy are identical twins. They have an older biological brother called Dave.

(a) Explain why Dave and Roy have the same natural hair colour but different eye colours.

(2 marks)

(b) Roy is a much better runner than Kevin.

Suggest **one** factor that may cause this difference in sporting ability.

(1 mark)

(c) Colour blindness is caused by a recessive faulty allele on the X chromosome.

Kevin and Roy are both colour blind, but Dave is not.
Explain whether or not their mother is colour blind.

(4 marks)

3 Kaye and Mark are expecting a baby. They already have three daughters.

(a) State the probability that Kaye and Mark will have another baby girl.

(1 mark)

(b) Kaye has dimples in her cheeks, but Mark does not. The presence of dimples is thought to be caused by a dominant allele represented by the letter **D**. The recessive allele is represented by the letter **d**. Kaye is heterozygous for the dimples gene.

Predict the ratio of dimpled to undimpled children amongst Kaye and Mark's offspring. Draw a Punnet square to explain your answer.

(2 marks)

(c) Kaye and Mark have a baby boy. A blood test shows that he has type O blood. Explain how you know that neither Mark or Kaye has type AB blood.

(2 marks)

4 Family pedigrees can show the inheritance of genetic disorders, such as cystic fibrosis. **Figure 1** is a family pedigree showing the inheritance of cystic fibrosis in a family.

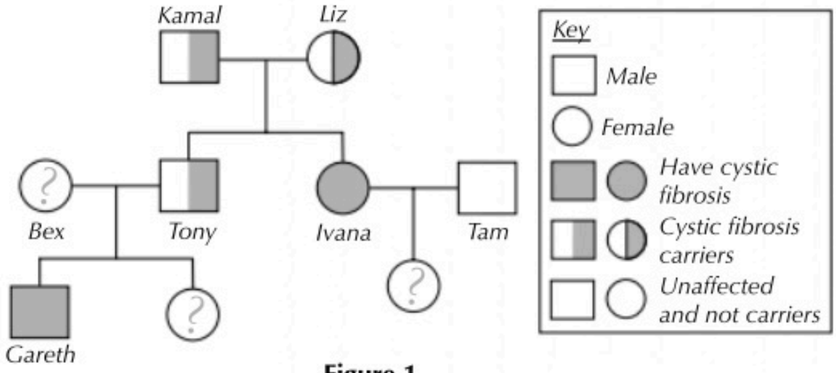


Figure 1

(a) Is Gareth heterozygous or homozygous for the cystic fibrosis allele? Explain your answer.

(1 mark)

f represents the allele for cystic fibrosis and **F** represents the healthy allele.

(b) Bex and Tony have a child with cystic fibrosis. Bex does not have cystic fibrosis.

State the combination of alleles Bex must have for the cystic fibrosis gene. Explain your answer.

(2 marks)

(c) Looking at the family pedigree, could Ivana and Tam have a child with cystic fibrosis? Draw a Punnett square to explain your answer.

(2 marks)

1. Natural Selection and Evidence for Evolution

The very first organisms on Earth, were simple and single-celled. Evolution is how those organisms became the many, complex species we know today.

What is evolution?

Evolution is the slow and continuous change of organisms' inherited characteristics from one generation to the next. The scientist Charles Darwin came up with the theory of natural selection to explain how evolution occurs.

The theory of evolution by natural selection

Scientists have developed Darwin's theory over time, using what we now know about genetics. It works like this:

1. Individuals in a population show genetic variation — differences in their characteristics that are caused by different **alleles** (see page 117). New alleles arise through **mutations** (see page 118).
2. Things like predation, competition for resources (e.g. food, water, mates, etc.) and disease act as **selection pressures**. This means they affect an organism's chance of surviving and reproducing.
3. Those individuals with characteristics that make them better adapted to the selection pressures in their environment have a better chance of survival and so are more likely to breed successfully.
4. This means the alleles that are responsible for the useful characteristics are more likely to be passed on to the next generation.
5. However, some individuals will be less well adapted to the selection pressures in their environment and may be less able to compete. These individuals are less likely to survive and reproduce.
6. The beneficial characteristics become more common in the population over time.

Evidence for evolution — antibiotic resistance

Antibiotics are drugs that are designed to kill bacteria or prevent them from reproducing.

Like all organisms, bacteria sometimes develop random mutations in their DNA. These can create new alleles which can change the bacteria's characteristics, e.g. being less affected by a particular antibiotic.

Learning Objectives:
- Be able to explain Darwin's theory of evolution by natural selection.
- Be able to explain how the emergence of resistant organisms supports Darwin's theory of evolution including antibiotic resistance in bacteria.

Specification References 4.2, 4.3

Tip: Darwin published his theory in 1859 — over 150 years ago.

Tip: Alleles are versions of genes (see page 101). Alleles are also known as genetic variants.

Tip: A species that can't compete is likely to become extinct (die out).

Exam Tip
You need to learn how bacteria evolve to become antibiotic resistant for your exam.

Tip: Antibiotic-resistant strains are a problem for people who become infected with these bacteria because they aren't immune to the new strain and there is no effective treatment. 'Superbugs' (e.g. MRSA) that are resistant to most known antibiotics are getting more common.

For the bacterium, the ability to resist this antibiotic is a big advantage. In a host who's being treated to get rid of the infection, a resistant bacterium is better able to survive than a non-resistant bacterium. This means it lives for longer and reproduces many more times — and so the allele for antibiotic resistance is passed on to lots of offspring (see Figure 1).

This is how antibiotic resistance spreads and becomes more common in a population of bacteria over time.

Tip: It's easy to see evolution happening in bacteria because they reproduce so rapidly.

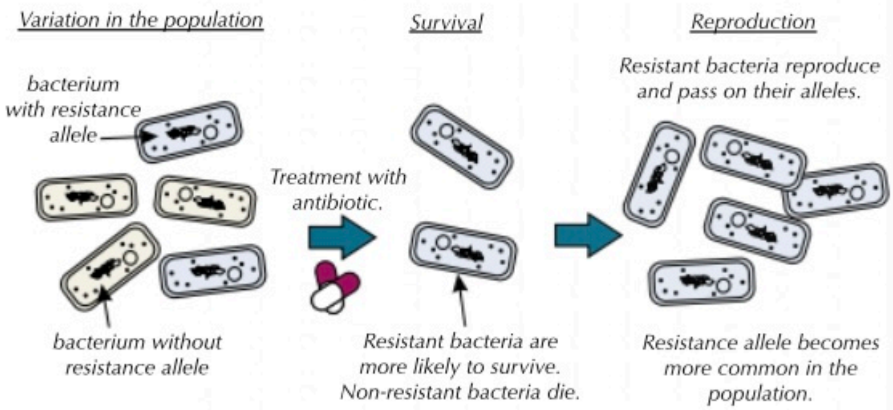

Variation in the population
bacterium with resistance allele
bacterium without resistance allele
Survival
Treatment with antibiotic.
Resistant bacteria are more likely to survive. Non-resistant bacteria die.
Reproduction
Resistant bacteria reproduce and pass on their alleles.
Resistance allele becomes more common in the population.

Figure 1: *Diagram to show how antibiotic resistance develops.*

The emergence of antibiotic resistance provides evidence for evolution because it's an example of natural selection taking place that we can observe. Antibiotic resistance makes the bacteria better adapted to an environment in which a selection pressure (antibiotics) are present. As a result, antibiotic resistance becomes more common in the population over time.

Tip: Natural selection is a theory — an accepted hypothesis (see p.2). Evidence is really important when it comes to accepting or rejecting scientific hypotheses — if there's no evidence to support a hypothesis, it won't become a theory.

WORKING SCIENTIFICALLY

Other organisms have developed resistance to chemicals that are designed to kill them too — e.g. many rats are now resistant to the chemical Warfarin™ (which used to be used to kill rats). The emergence of these organisms also provides evidence for evolution.

Evidence for evolution — fossils

A fossil is any trace of an animal or plant that lived a long time ago (usually many millions of years ago). They are most commonly found in rocks. Generally, the deeper the rock, the older the fossil.

Figure 2: *A fossil of a dinosaur's skull.*

By arranging fossils in chronological (date) order, gradual changes in organisms can be observed. This provides evidence for evolution, because it shows how species have changed and developed over billions of years. Fossils that provide evidence for human evolution are covered on pages 130-131.

Practice Questions — Fact Recall

Q1 How do new alleles arise in a population?

Q2 What is a selection pressure?

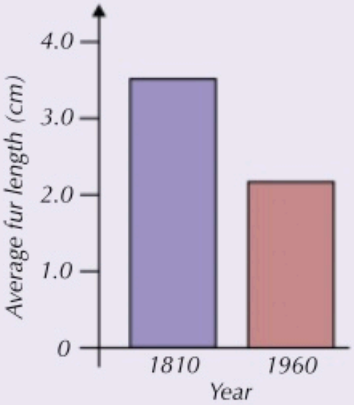
Q3 True or false? Organisms that are less well adapted to the selection pressures in their environment are better able to compete.

Practice Questions — Application

Q1 Glyphosate is a chemical that is commonly used in weedkillers. Some weeds have become resistant to it.

Use the theory of evolution by natural selection to explain how a population of weeds could become glyphosate-resistant.

Q2 In 1810, a herd of reindeer were taken from the Arctic to an area with a warmer climate. The herd were then left to live and reproduce in the area and were revisited in 1960.
Some information about the herd is shown in the graph.



a) By roughly how much did the average fur length of the herd change between 1810 and 1960?

b) Explain this change in terms of natural selection.

Tip: To help you answer Q2 b), think about how the change in fur length might affect the reindeer in their new environment.

Learning Objective:

- Be able to describe the work of Darwin and Wallace in the development of the theory of evolution by natural selection and explain the impact of these ideas on modern biology.

Specification Reference 4.1B

2. Darwin and Wallace

You might remember from page 125, that the scientist Charles Darwin came up with the theory of evolution by natural selection. However, he wasn't the only person involved in developing the theory. Read on for more...

Charles Darwin

Charles Darwin first published his theory of evolution by natural selection in 1859, in a famous book called 'On the Origin of Species'.

Before that, he spent 5 years on a voyage around the world studying plants and animals on a ship called HMS Beagle. Whilst on his travels, he noticed that there was variation in members of the same species and that those with characteristics most suited to the environment were more likely to survive. He also noticed that characteristics could be passed on to offspring.

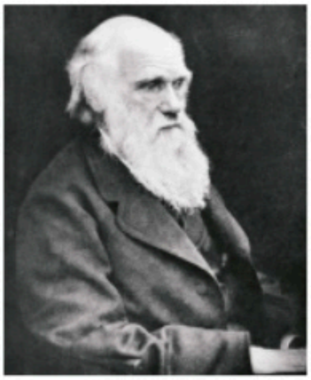


Figure 1: *Darwin.*

Darwin wrote his theory of evolution by natural selection to explain his observations. DNA and genes hadn't been discovered when Darwin was doing his work, so he didn't know exactly how characteristics were passed on — these details were added to the theory much later on.

Alfred Russel Wallace

Alfred Russel Wallace was a scientist working at the same time as Darwin. He also came up with the idea of natural selection, independently of Darwin. He and Darwin published their papers on evolution together and acknowledged each other's work — although they didn't always agree on the mechanisms involved in natural selection.

Figure 2: *Wallace (who, in this photo, looks uncannily similar to Darwin).*

Wallace's observations provided lots of evidence to help support the theory of evolution by natural selection.

Example

Wallace realised that warning colours are used by some species (e.g. butterflies) to deter predators from eating them — an example of a beneficial characteristic that had evolved by natural selection.

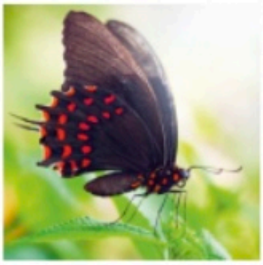


Figure 3: *Any birds thinking of eating this butterfly are likely to be put off by its red and black warning colours.*

But it was Darwin's 'On the Origin of Species' that made other scientists pay attention to the theory. In this book Darwin gave lots of evidence to support the theory and expanded on it. This book is partly why Darwin is usually better remembered than Wallace.

Influence on modern biology

The theory of evolution by natural selection is still relevant today — it helps us to understand many areas of biology.

We now understand that all life changes through the process of evolution, and that the evidence suggests we have all descended from a common ancestor. This has affected lots of different areas of biology, including:

Example

- Classification — if all living organisms have descended from a common ancestor, then we're all related in some way. We now classify organisms (arrange them into groups) based on how closely related they are (see pages 136-137).
- Antibiotic resistance (see pages 125-126) — we now understand the importance of finishing the course of drugs to prevent resistant bacteria spreading and we know we need to constantly develop new antibiotics to fight newly evolved resistant bacteria.
- Conservation — we now understand the importance of genetic diversity (having a variety of different alleles in a population) and how it helps populations adapt to changing environments. This has led to conservation projects that aim to maximise genetic diversity in order to protect species.

Practice Questions — Fact Recall

Q1 Outline the work Darwin did, including the observations he made, which led to him proposing the theory of evolution by natural selection.

Q2 Darwin's theory of evolution by natural selection was published in 1859. Since then, some additional details have been added to the theory to help explain how evolution occurs. Give an example of one of these details.

Q3 Describe Wallace's contribution to the theory of evolution by natural selection.

Q4 Give two areas of modern biological research that have been influenced by the theory of evolution by natural selection.

3. Evidence for Human Evolution — Fossils

Learning Objective:
- Be able to describe the evidence for human evolution, based on fossils, including:
  - Ardi from 4.4 million years ago,
  - Lucy from 3.2 million years ago,
  - Leakey's discovery of fossils from 1.6 million years ago.

Specification Reference 4.4

Like all organisms alive today, humans have evolved from other, less complex organisms. The evidence for this comes from fossils.

Who did humans evolve from?

Evidence from fossils suggests that humans and chimpanzees evolved from a common ancestor — a species of ape that existed around 6 million years ago.

Human beings and their ancestors are known as **hominids**. Fossils of several different hominid species have been found. These fossils have characteristics that are between apes and humans — by looking at hominid fossils you can see how humans have evolved over time.

Tip: An ancestor is a relative that lived a long time before you, e.g. your grandad's grandad. If two species have a common ancestor, it means that they are both descended from the same ancestor.

Example

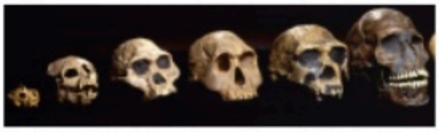


Figure 1: *A series of hominid skulls.*

Figure 1 shows a selection of hominid skulls. The skulls are arranged in chronological (date) order, with the oldest skulls on the left. You can see that the oldest skulls are smaller and more ape-like. The skulls gradually get more human-like as you go from left to right. The skull on the far right is 92 000 years old. It belonged to a modern human (*Homo sapiens*).

Hominid fossils

Certain hominid fossils have been found that are key to our understanding of how humans evolved. These include the fossils known as "Ardi" and "Lucy", as well as the fossils discovered by the scientist Richard Leakey and his team in Kenya. You need to learn about them all for your exam.

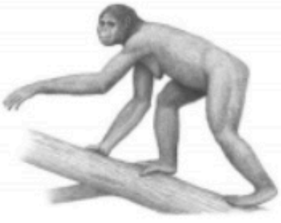


Figure 2: *An artist's sketch of what Ardi might have looked like. Here, she's shown climbing a tree.*

"Ardi"

Ardi is a hominid fossil of the species *Ardipithecus ramidus*. She was found in Ethiopia and is 4.4 million years old. Ardi's features are a mixture of those found in humans and in apes:

- The structure of her feet suggests she climbed trees — she had an ape-like big toe to grasp branches.
- She also had long arms and short legs (more like an ape than a human).
- Her brain size was about the same as a chimpanzee's.
- But the structure of her legs suggests that she walked upright. Her hand bone structure also suggests she didn't use her hands to help her walk (like apes do).

Tip: Brain size is found by working out 'cranial capacity' — the space taken up by the brain in the skull.

"Lucy"

Lucy is a hominid fossil of the species *Australopithecus afarensis*. She was found in Ethiopia and is 3.2 million years old. Lucy also has a mixture of human and ape features, but she is more human-like than Ardi.

- Lucy had arched feet, more adapted to walking than climbing, and no ape-like big toe.
- The size of her arms and legs was between what you would expect to find in apes and humans.
- Her brain was slightly larger than Ardi's but still similar in size to a chimp's brain.
- The structure of Lucy's leg bones and feet suggest she walked upright, but more efficiently than Ardi.

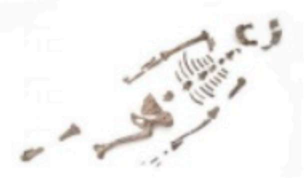


Figure 3: *The remains of Lucy's skeleton. Although the remains are incomplete, other fossils of the same species have been found, which tell us more about her.*

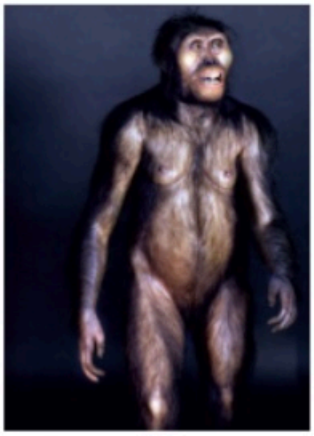


Figure 4: *A model made to show what Lucy might have looked like when she was alive.*

Leakey's fossils

In 1984 scientist Richard Leakey organised an expedition to Kenya to look for hominid fossils. He and his team discovered many important fossils of different *Australopithecus* and *Homo* species.

- One of their finds was "Turkana Boy" — a 1.6 million year old fossil skeleton of the species *Homo erectus*. He has a mixture of human and ape-like features, but is more human-like than Lucy.
- His short arms and long legs are much more like a human than an ape, and his brain size was much larger than Lucy's — similar to human brain size.
- The structure of his legs and feet suggest he was even better adapted to walking upright than Lucy.

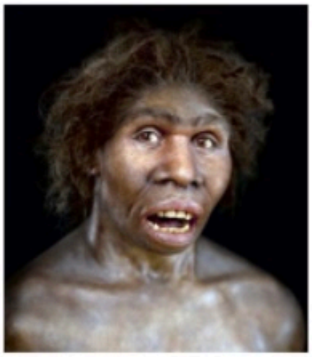


Figure 5: *A model made to show what Turkana Boy might have looked like.*

A timeline of human evolution

So you know that the *Ardipithecus* and *Australopithecus* species were more ape-like, compared to the *Homo* species, which are human-like.

They can all be put on a timeline, showing how humans have evolved — see Figure 6.

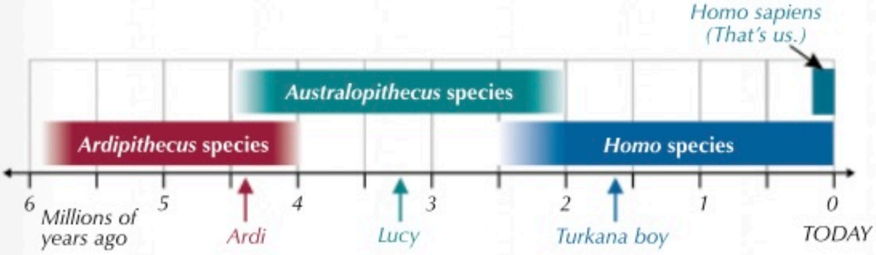


Figure 6: *A timeline showing humans and their ancestors (hominids).*

Tip: Turkana Boy was more closely related to modern humans than either Lucy or Ardi — that's why his model looks more like us than Lucy's model does.

Practice Questions — Fact Recall

Q1 Briefly explain how hominid fossils provide evidence for human evolution.

Q2 True or false? The fossil "Ardi" is younger than the fossil "Lucy".

Q3 Briefly describe the fossil "Turkana Boy" discovered by Richard Leakey and his team. Include the age of the fossil.

Practice Questions — Application

Q1 For each of the fossils described below, state whether it is "Ardi", "Lucy" or Richard Leakey's "Turkana Boy".

A This fossil is 3.2 million years old. The size of the arms and legs are in between what you would expect to find in apes and humans.

B This fossil has long arms and short legs similar to those of an ape. It also has an ape-like big toe.

C This fossil has short arms and long legs. The skulls suggests that the brain size was similar to a human brain size.

Q2 Put the fossils described in Q1 in age order, starting with the oldest.

Q3 A scientist finds a hominid fossil that is more recent than Lucy. How would you expect the arm and leg lengths of this fossil to compare to Lucy's?

4. Evidence for Human Evolution — Stone Tools

Fossils of hominid remains aren't the only evidence for human evolution — the tools they used also gives us clues about how we evolved.

Tool development

The different *Homo* species (see page 131) continued to evolve. You can tell this because they started using stone tools and these gradually became more complex — so their brains must have been getting larger.

Homo habilis

Homo habilis lived between 2.5 and 1.5 million years ago. They made simple stone tools called pebble tools by hitting rocks together to make sharp flakes. These could be used to scrape meat from bones or crack bones open.

Homo erectus

Homo erectus lived between 2 and 0.3 million years ago. They sculpted rocks into shapes to produce more complex tools like simple hand-axes. These could be used to hunt, dig, chop and scrape meat from bones.

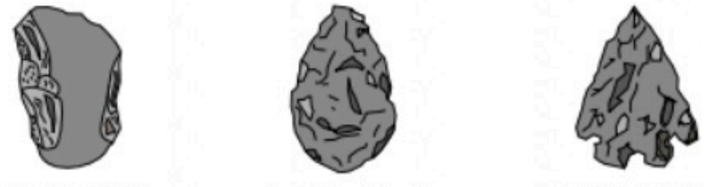
Homo neanderthalensis

Homo neanderthalensis lived between 300 000 and 25 000 years ago. They made even more complex tools. There is evidence that they used flint tools, with sharp, pointed edges, and wooden spears.

Homo sapiens

Homo sapiens are modern humans. The first *Homo sapiens* appeared about 200 000 years ago. By this point flint tools were widely used. More complex pointed tools, including fish hooks, needles and arrowheads appeared around 50 000 years ago.

Some of these developments are summarised in Figure 2.



A simple pebble tool made by Homo habilis.

A sculpted hand axe made by Homo erectus.

A pointed flint arrowhead made by Homo sapiens.

Figure 2: *A diagram to show how stone tools have increased in complexity over time.*

Learning Objective:

- Be able to describe the evidence for human evolution based on stone tools, including:
  - the development of stone tools over time;
  - how these can be dated from their environment.

Specification Reference 4.5

Figure 1: *A selection of flint tools.*

Tip: Flint is a type of hard, sedimentary rock. It can be used to make tools because it splits into thin layers, with a sharp edge (called flakes) when struck with a hammer or other similar object. Flint tools are more difficult to make than, e.g. a simple pebble tool.

Exam Tip

You don't need to learn the names of the different hominid species for your exam, but you might see them used in exam questions — don't be thrown by it.

Dating stone tools and fossils

When an ancient stone tool or hominid fossil (see page 130) is found, scientists need to be able to work out how old it is. There are several different ways they can try to do this. These include:

- Looking at the structural features of the tool or fossil.
  For example, simpler tools are likely to be older than more complex tools.
- Using **stratigraphy** — the study of rock layers. For a tool or fossil to be found in a rock layer, it must have been present at the time the layer was formed. Older rock layers are normally found below younger layers, so tools or fossils in deeper layers are usually older — see Figure 3.

Tip: Dating tools and fossils isn't always very accurate, e.g. rock layers can move over time.

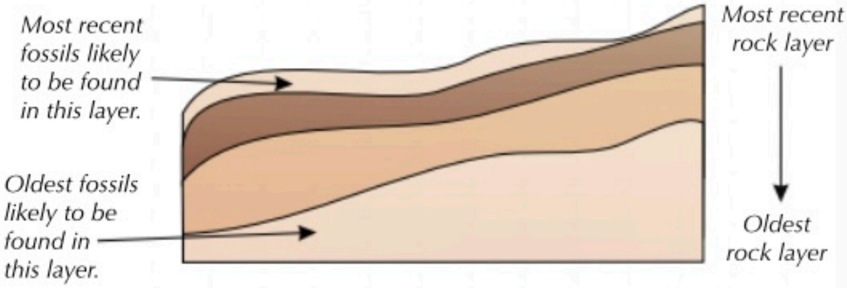

Most recent fossils likely to be found in this layer.
Oldest fossils likely to be found in this layer.
Most recent rock layer
Oldest rock layer

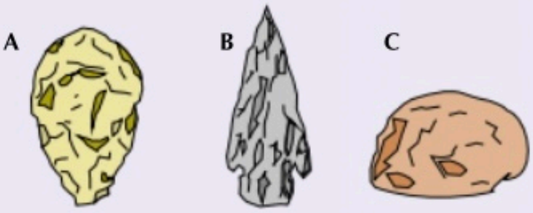
Figure 3: *A diagram to show how stratigraphy works.*

- Stone tools are often found with carbon-containing material, e.g. a wooden handle. A process called carbon-14 dating can be used to date this material. Carbon-14 dating works on the basis that all carbon-based material contains a small amount of a radioactive form of carbon called ^{14}C and that the amount of ^{14}C decreases over time as it decays. Carbon-14 dating is a form of radiometric dating and other methods of radiometric dating can be used to date the rocks that tools or fossils are found in. These methods include potassium-argon and uranium-lead dating.

Tip: Carbon-14 dating only works to date carbon-containing material that's around 70 000 years old or less. Both potassium-argon and uranium-lead dating can be used to date materials that are billions of years old.

Practice Questions — Application

Q1 Three stone tools are shown below.



a) Using only the structural features of the tools, put the tools in the most likely order of age, starting with the oldest.

b) Give reasons for your answer to part a).

c) Which tool is most likely to have been made by modern humans?

d) The tool labelled A was found in a layer of rock above the tool labelled C. Does this support or contradict your answer to part a)? Explain your answer.

5. The Pentadactyl Limb

The pentadactyl limb also provides evidence for evolution — not just for the evolution of humans, but for the evolution of all organisms with four limbs.

Learning Objective:

- Be able to describe how the anatomy of the pentadactyl limb provides scientists with evidence for evolution.

Specification Reference 4.6B

What is a pentadactyl limb?

A pentadactyl limb is a limb with five digits. You can see the pentadactyl limb in all organisms with four limbs, including mammals, birds, reptiles and amphibians. In each of these groups of animals, the pentadactyl limb has a similar bone structure, but usually a different function.

Tip: A limb is an arm, leg or wing. A digit is the end part of a limb, e.g. a finger or toe.

Example

A human's hand and a bat's wing are both pentadactyl limbs — and they look pretty alike — see Figure 1. Obviously though, we can't use our pentadactyl limbs to fly.

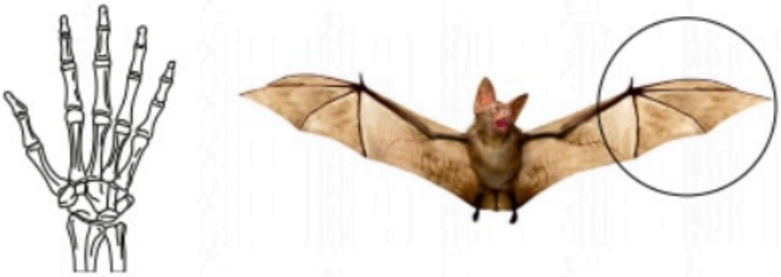


Figure 1: *A human hand (left) and a bat's wings (right). The five digits in the bat's wing are circled.*

Tip: Some modern organisms with a pentadactyl limb, e.g. birds, have actually lost some of their 5 digits through further evolution.

Evidence for evolution

The similarity in bone structure provides evidence that species with a pentadactyl limb have all evolved from a common ancestor (that had a pentadactyl limb). If they'd all evolved from different ancestors, it'd be highly unlikely that they'd share a similar bone structure.

Practice Question — Application

Q1 The photos below show the pentadactyl limbs of a whale and a bird. Explain why having these limbs suggests that whales and birds are descended from a common ancestor.

Learning Objective:

- Be able to describe how genetic analysis has led to the suggestion of the three domains rather than the five kingdoms classification method.

Specification Reference 4.7

6. Classification

Classification means sorting things into groups — like organisms, for example. The way in which we classify organisms has changed over time and with advances in scientific knowledge and technology.

Five kingdom classification

Traditionally, organisms were classified according to similarities and differences in their observable characteristics, i.e. things you can see (like how many legs something has). As technology improved, this included things you can see with a microscope, e.g. cell structure.

These characteristics were used to classify organisms in the five kingdom classification system. In this system, living things are first divided into five groups called kingdoms. These are:

- Animals — fish, mammals, reptiles, etc.
- Plants — grasses, trees, etc.
- Fungi — mushrooms and toadstools, yeasts, mould.
- Prokaryotes — all single-celled organisms without a nucleus (e.g. bacteria).
- Protists — eukaryotic single-celled organisms, e.g. algae.

Tip: All eukaryotic organisms have a nucleus in their cells. There's more on eukayotic and prokaryotic organisms on pages 23-24.

The kingdoms are then subdivided into smaller and smaller groups that have common features — phylum, class, order, family, genus, species.

The five kingdom classification method is illustrated in Figure 1.

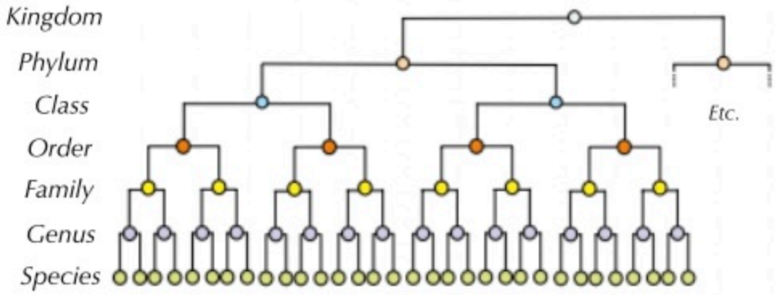


Figure 1: *Diagram to show the five kingdom system of classification.*

Tip: Remember, it's the sequence of DNA bases in a gene that codes for a protein — see p.93.

Tip: In order to make proteins, the code in DNA is first copied over into another molecule called RNA. The RNA has a complementary base sequence to DNA. See page 95 for more.

Three domain classification

The five kingdom classification system is still used, but it's now a bit out of date.

Over time, technology has developed further and our understanding of things like biochemical processes and genetics has increased. For example, we are now able to determine the sequence of DNA bases in different organisms' genes and compare them — the more similar the sequence of a gene, the more closely related the organisms. Scientists are also able to compare RNA sequences in a similar way.

Example

The diagram below shows part of the DNA base sequence for a particular protein in found in three different species.

Species A: ATTGTCTGATTGGTGCTAGTCGTCGATGCTAGGATCG

Species B: ATTGTATGATTGGTGCTAGTCGGCGATGCTAGGATCG

Species C: ATTGATTGAAAGGAGCTACTCGTAGATATAAGGAGGT

There are 13 differences between the base sequences in species A and C, but only 2 differences between the base sequences in species A and B. This suggests that species A and B are more closely related than A and C.

Tip: More closely related species will have more classification groups in common. E.g. humans and apes share all the same classification groups down to family, but humans and mice only share them down to class — they are not part of the same order or family.

Genetic analysis led to a bit of a rethink about the way organisms are classified and to the proposal of the three domain system of classification by a scientist called Carl Woese.

Using RNA sequencing, Woese found that some members of the Prokaryote kingdom were not as closely related as first thought. He proposed that this kingdom should be split into two groups called Archaea and Bacteria. Organisms in the Archaea domain look similar to bacteria but are actually quite different (as their DNA and RNA sequences show). The Bacteria domain contains "true bacteria" — for example *E. coli* and *Chlamydia*.

Tip: Archaea were first found in extreme places such as hot springs and salt lakes.

In fact, Woese suggested that all organisms should first be divided into three large groups called domains. Archaea and Bacteria are two of these domains. The third domain is Eukarya — all eukaryotic organisms are in this domain.

The three domains are then subdivided into smaller groups used in the five kingdom classification system (beginning with kingdom and finishing with species). The three domain system of classification is summarised in Figure 2.

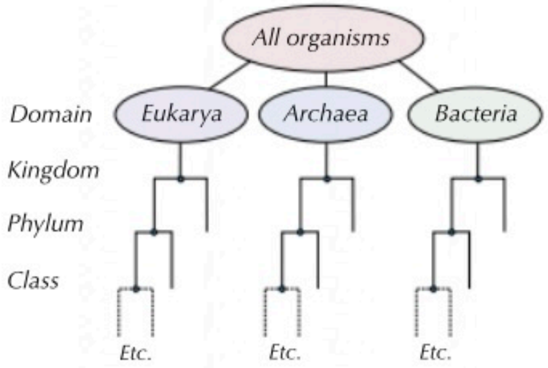


Figure 2: *Diagram to show the three domain system of classification.*

Practice Questions — Fact Recall

Q1 What is the smallest group in the five kingdom classification system?
A kingdom B class C species D genus

Q2 Explain how the three domain classification system was developed.

Q3 Name each of the three domains.

Topic 4a Checklist — Make sure you know...

Natural Selection and Evidence for Evolution

- ☐ How to explain Darwin's theory of evolution by natural selection. Genetic variation in a population gives some organisms a survival advantage over others when faced with certain selection pressures. The better adapted organisms are more likely to survive, reproduce and pass on the alleles that control their advantageous characteristic(s) to their offspring.
- ☐ How the spread of antibiotic resistance in bacterial populations provides evidence for evolution.

Darwin and Wallace

- ☐ That Darwin and Wallace each independently came up with the theory of evolution by natural selection.
- ☐ About the work Darwin did to come up with the theory of evolution by natural selection.
- ☐ About some of the evidence Wallace found to support the theory of evolution by natural selection.
- ☐ How Darwin and Wallace's ideas influence modern biology — for example, in the areas of classification, antibiotic resistance and drug development, and conservation.

Evidence for Human Evolution — Fossils

- ☐ That "Ardi" (4.4 million years old) and "Lucy" (3.2 million years old) are fossils of human ancestors, as are the fossils discovered by Richard Leakey (for example, "Turkana Boy", which is 1.6 million years old).
- ☐ How Ardi, Lucy and Leakey's fossils (e.g. Turkana Boy) provide evidence for the evolution of humans from an ape ancestor.

Evidence for Human Evolution — Stone Tools

- ☐ That human ancestors used stone tools, which became more complex over time, providing evidence to suggest that these ancestors were evolving (and their brain size was increasing).
- ☐ How stone tools and fossils can be dated by their structural features and by their environment — for example, by studying the rock layers in which the tools and fossils were found or by carbon-14 dating any carbon-containing material the tools and fossils were found with.

The Pentadactyl Limb

- ☐ How the pentadactyl (five digit) limb shared by four-limbed organisms provides evidence that these organisms all evolved from a common ancestor.

Classification

- ☐ How advances in DNA and RNA sequencing led to the proposal of the three domain system of classification (in which prokaryotic organisms are split into the two separate domains of Archaea and Bacteria) instead of the five kingdom classification system.

Exam-style Questions

1 **Figure 1** shows a stone hand axe from South Africa that's about 1.5 million years old.

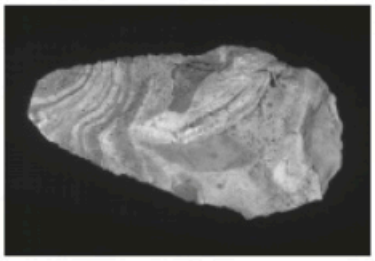


Figure 1

(a) Describe **one** way in which scientists could have determined the age of the hand axe in **Figure 1** from its surroundings.

(1 mark)

(b) "Lucy" is a fossil of the species *Australopithecus afarensis*.

(i) Approximately how much older is "Lucy" than the hand axe in **Figure 1**?

A 0.1 million years
B 1.2 million years
C 1.7 million years
D 2.9 million years

(1 mark)

(ii) When she was alive, Lucy is not likely to have used tools like the one in **Figure 1**. Explain why.

(2 marks)

2 **Figure 2** shows a type of snake called a Sinaloan milk snake.

The milk snake is relatively harmless, but it has evolved to have a very similar pattern and colouring to the deadly poisonous coral snake, which lives in the same environment. The coral snake's colouring warns predators that it is dangerous to eat.

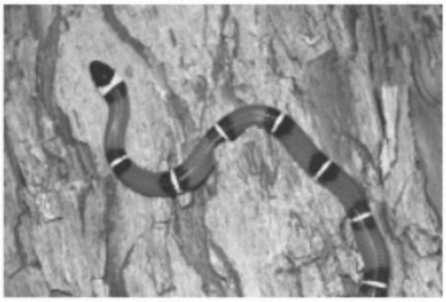


Figure 2

(a)* Using the idea of natural selection, explain how the milk snake may have evolved to have a similar colouring to the coral snake.

(6 marks)

(b) The theory of evolution by natural selection was proposed by Charles Darwin. Name **one** other scientist who worked on the theory.

(1 mark)

1. Selective Breeding

Learning Objectives:

- Be able to explain selective breeding and its impact on food plants and domesticated animals.
- Be able to evaluate the benefits and risks of selective breeding in modern agriculture and medicine, including practical and ethical implications.

Specification References 4.8, 4.14

Selective breeding is all about getting the characteristics you want in animals and plants.

What is selective breeding?

Selective breeding is when humans artificially select the plants or animals that are going to breed so that the genes for particular characteristics remain in the population. Organisms are selectively bred to develop features that are useful or attractive:

Examples

- Animals that produce more meat or milk.
- Crops with disease resistance.
- Dogs with a good, gentle temperament.
- Plants that produce bigger fruit.

The process of selective breeding

Tip: Selective breeding is also known as 'artificial selection'.

This is the basic process involved in selective breeding:

1. From your existing stock, select the ones which have the characteristics you're after.
2. Breed them with each other.
3. Select the best of the offspring, and breed them together.
4. Continue this process over several generations, and the desirable trait gets stronger and stronger. Eventually, all the offspring will have the characteristic.

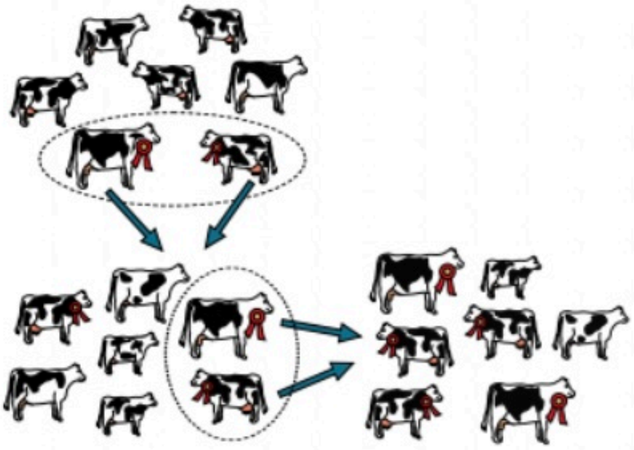


Figure 1: *Diagram showing the best offspring being selectively bred together over many generations — the desirable trait becomes more common.*

Exam Tip
You could be asked how an organism would be selectively bred for a characteristic you've not come across before. Don't worry — the general process would still be exactly the same.

Selective breeding is nothing new — people have been doing it for thousands of years. It's how we ended up with edible crops from wild plants and how we got domesticated animals like cows and dogs.

Uses of selective breeding

In agriculture (farming), selective breeding can be used to improve yields (the amount of food a crop or some livestock produce).

Example

Genetic variation (see page 117) means that some cattle will have better characteristics for producing meat than others (e.g. a larger size).

To improve meat yields, a farmer could select the cows and bulls with these characteristics and breed them together. After doing this, and selecting the best of the offspring for several generations, the farmer would get cows with a very high meat yield.

Figure 2: *The Belgian Blue breed of cow has been produced by selective breeding to produce lots of meat.*

Selective breeding can also be used in medical research.

Example

In several studies investigating the reasons behind alcoholism, rats have been bred with either a strong preference for alcohol or a weak preference for alcohol. This has allowed researchers to compare the differences between the two different types of rats, including differences in their behaviour and in the way that their brains work.

Tip: Selective breeding can be used to improve yields with plants too, e.g. it can be used to increase the amount of grain produced by a cereal crop.

Reducing the gene pool

The main problem with selective breeding is that it reduces the gene pool — the number of different alleles (forms of a gene) in a population. This is because the farmer keeps breeding from the "best" animals or plants — which are all closely related. This is known as **inbreeding**.

Inbreeding can cause health problems because there's more chance of the organisms inheriting harmful genetic defects when the gene pool is limited. Some dog breeds are particularly susceptible to certain defects because of inbreeding (e.g. pugs often have breathing problems). This leads to ethical considerations — particularly if animals are deliberately bred to have negative characteristics for medical research.

There can also be serious problems if a new disease appears. There's not much variation in the population, so there's less chance of resistance alleles being present. All the stock are closely related to each other, so if one of them is going to be killed by a new disease, the others are also likely to succumb to it.

Practice Questions — Fact Recall

Q1 Outline the process of selective breeding.

Q2 Explain one problem associated with selective breeding.

2. Tissue Culture

Learning Objective:
- Be able to describe the process of tissue culture and its advantages in plant breeding programmes and medical research.

Specification Reference 4.9B

Tissues are groups of similar cells that work together to perform a particular function. Tissues can be grown outside of a living organism using a process called tissue culture...

What is tissue culture?

Tissue culture is when cells are grown on or in an artificial growth medium. The growth medium is usually something like agar jelly or a liquid broth.

Scientists can use tissue culture to produce whole plants from the cells of a single individual. Tissue culture can't be used to grow whole animals, but it can be used to produce cells and tissues for use in medical research.

Plant tissue culture

It's very easy to grow whole plants via tissue culture, and very useful too. Plants grown this way can be made very quickly, in very little space and can be grown all year.

The plants produced via tissue culture are also **clones** — genetically identical organisms. Scientists can use tissue culture to create lines of clones all with the same beneficial features, e.g. pesticide resistance, tasty fruit, etc.

Here's how it works:

1. First you choose the plant you want to clone, usually based on its characteristics — e.g. a beautiful flower, a good fruit crop.
2. You remove several small pieces of tissue from the parent plant. You get the best results if you take tissue from fast-growing root or shoot tips.
3. You grow the tissue on a growth medium containing nutrients and growth hormones. This is done under aseptic (sterile) conditions to prevent growth of microbes that could harm the plants.
4. As the tissues produce shoots and roots they can be moved to potting compost to carry on growing.

Tip: Selective breeding involves sexual reproduction, which results in genetically varied offspring (see p.84-85). This means that the offspring might not inherit the characteristics you want. With plant tissue culture, the offspring will be genetically identical to the parent plant — so you can be sure of their characteristics.

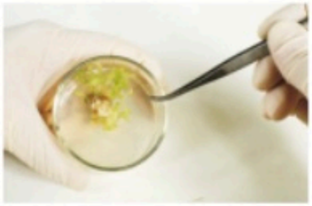


Figure 1: *A tobacco plant being grown by tissue culture.*

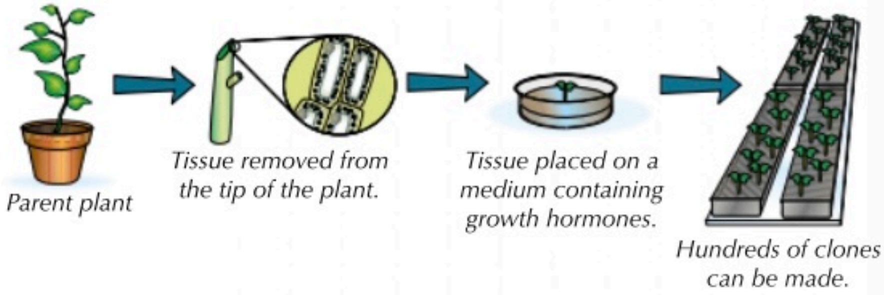

Parent plant
Tissue removed from the tip of the plant.
Tissue placed on a medium containing growth hormones.
Hundreds of clones can be made.

Figure 2: *Diagram to show how tissue culture can be used to clone plants.*

Animal tissue culture

Animal tissue culture is often used in medical research because it means that you can carry out all kinds of experiments on tissues in isolation (e.g. you can investigate the effect of glucose on cells in the pancreas by growing pancreatic cells in culture). This means that you can look at the effects of a particular substance or environmental change on the cells of a single tissue, without complications from other processes in the whole organism.

Tip: Research involving animal tissues rather than whole animals can also avoid some of the ethical issues surrounding animal testing (however, the law currently states that medicines must be tested on whole animals as well as animal tissues).

Tissue culture of animal cells is carried out as follows:

1. First, a sample of the tissue you want to study, e.g. tissue from the pancreas, is extracted from the animal.
2. The cells in the sample are separated from each other using enzymes.
3. Then they are placed in a culture vessel and bathed in a growth medium containing all the nutrients that they need. This allows them to grow and multiply.
4. After several rounds of cell division, the cells can be split up again and placed into separate vessels to encourage further growth.
5. Once the tissue culture has been grown, it can be stored for future use.

Tip: The cells produced by animal tissue culture are also clones.

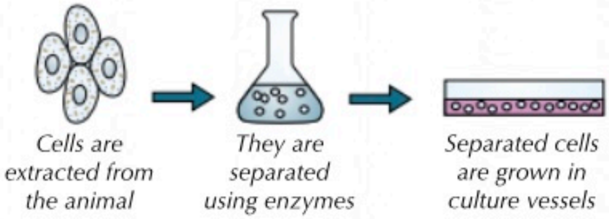

Cells are extracted from the animal
They are separated using enzymes
Separated cells are grown in culture vessels

Figure 3: *Diagram to show how tissue culture can be used to grow animal cells.*

Practice Question — Fact Recall

Q1 What is tissue culture?

Practice Questions — Application

Q1 A scientist is trying to save a rare species of orchid from extinction using tissue culture.

a) Describe a method of tissue culture that the scientist could use to grow more orchids.

b) Suggest one reason why the scientist might have chosen to use tissue culture to save the orchid.

Q2 Viruses infect animal cells and replicate inside them. Scientists trying to make vaccines against viruses need lots of animal cells for their research. Suggest why the scientists use tissue culture to produce these cells.

Tip: An orchid is a type of flowering plant.

Learning Objectives:

- Be able to describe genetic engineering as a process which involves modifying the genome of an organism to introduce desirable characteristics.
- **H** Be able to describe the main stages of genetic engineering including the use of: restriction enzymes, ligase, sticky ends, vectors.
- Be able to evaluate the benefits and risks of genetic engineering in modern agriculture and medicine, including practical and ethical implications.

Specification References 4.10, 4.11, 4.14

3. Genetic Engineering

Humans are able to change an organism's genes through a process called genetic engineering. It's really quite clever...

What is genetic engineering?

The basic idea of genetic engineering is to transfer a gene from one organism's genome into another organism's genome, in order to introduce a desirable characteristic. The organism into which the gene has been transferred is known as a **genetically modified** (**GM**) **organism** (or GMO).

Uses of genetic engineering

Scientists use genetic engineering to do all sorts of things:

Examples

- Bacteria have been genetically modified to produce human insulin that can be used to treat diabetes (see next page).
- GM crops have had their genes modified, e.g. to improve the size and quality of their fruit, or make them resistant to disease, insects and herbicides (chemicals used to kill weeds).
- Sheep and cows have been genetically engineered to produce useful human proteins in their milk, e.g. antibodies used in therapy to treat illnesses like arthritis, some types of cancer and multiple sclerosis.

Tip: In the future, it might be possible to do even more with genetic engineering. For example, produce animals with organs suitable for organ transplantation.

How genetic engineering works **Higher**

This is the process involved in genetic engineering:

1. The DNA (gene) that is going to be transferred is cut out with a **restriction enzyme**. Restriction enzymes recognise specific sequences of DNA and cut the DNA at these points. The cut leaves one of the DNA strands with unpaired bases — this is called a "**sticky end**".
2. The same restriction enzyme is used to cut open the **vector** DNA. A vector is something used to transfer DNA into a cell. It could be a plasmid (a small, circular molecule of DNA that can be transferred between bacteria) or a virus.
3. The vector DNA and the DNA you're inserting are left with complementary (matching) sticky ends. They are mixed together with **ligase** enzymes. Ligase joins the sticky ends together to produce recombinant DNA (two different bits of DNA stuck together).
4. The recombinant DNA (i.e. the vector containing the new DNA) is inserted into other cells, e.g. bacteria.
5. The cells can now use the inserted gene to make the protein it codes for.

Tip: **H** Plasmids occur naturally in many bacterial cells. See page 24 for more. Viruses naturally insert DNA into the organisms they infect.

Example **Higher**

The human insulin gene can be inserted into bacteria. The bacteria will then produce human insulin. This process is shown in Figure 1.

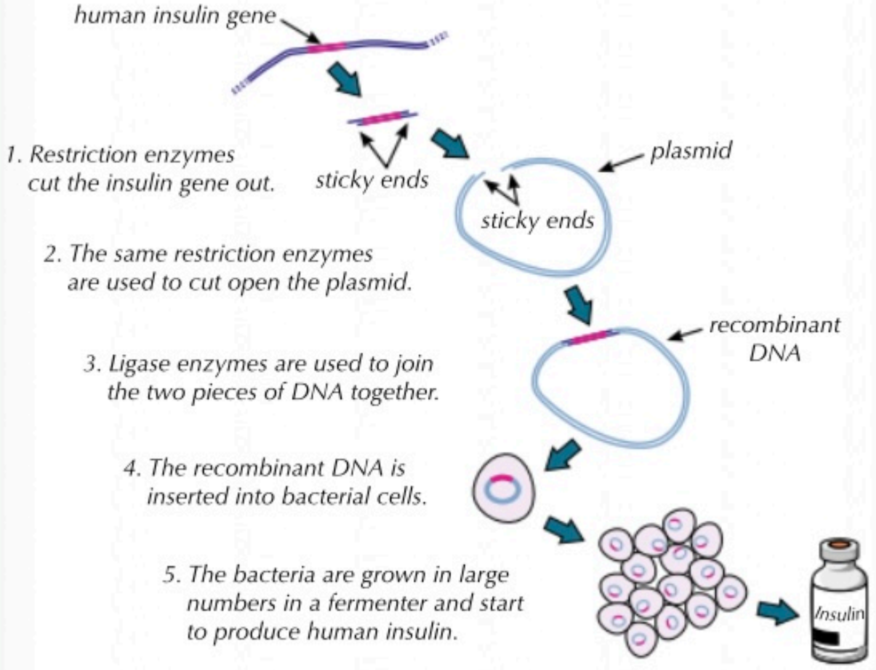

human insulin gene
1. Restriction enzymes cut the insulin gene out.
sticky ends
plasmid
sticky ends
2. The same restriction enzymes are used to cut open the plasmid.
recombinant DNA
3. Ligase enzymes are used to join the two pieces of DNA together.
4. The recombinant DNA is inserted into bacterial cells.
5. The bacteria are grown in large numbers in a fermenter and start to produce human insulin.
Insulin

Figure 1: *The steps involved in producing human insulin using genetically engineered bacteria.*

Figure 2: *Genetically engineered bacteria being grown in an industrial vat.*

Benefits and risks

Genetic engineering has a lot of benefits.

Examples

- In agriculture, genetically modifying crops to be herbicide-resistant means farmers can spray their crops to kill weeds, without affecting the crop itself. This can increase crop yield (the amount of food a crop produces).
- In medicine, genetically modifying bacteria has allowed human insulin for the treatment of diabetes to be produced relatively easily and cheaply in large quantities.

However, there are ethical concerns about the genetic engineering of animals. It can be hard to predict what effect modifying its genome will have on the organism — many genetically modified embryos don't survive and some genetically modified animals suffer from health problems later in life.

There are also practical concerns about growing genetically modified crops. One is that transplanted genes may get out into the environment, e.g. a herbicide resistance gene may be picked up by weeds, creating a new 'superweed' variety. Another concern is that genetically modified crops could adversely affect food chains — or even human health.

Tip: Insulin from pigs and cows used to be used to treat diabetes. However, some people have an adverse reaction to these animal insulins. They can also be difficult to obtain in large quantities.

Practice Questions — Fact Recall

Q1 What is genetic engineering?

Q2 What is the role of each of the following in genetic engineering:

a) restriction enzymes?

b) ligases?

c) vectors?

Practice Question — Application

Q1 There is a vaccine that protects against the liver disease hepatitis B. Like most vaccines it is injected using a needle (which must be sterilised). The vaccine must also be transported and stored in a refrigerator, which can be expensive.

Scientists are working on genetically modifying corn plants to produce the hepatitis B vaccine in their corn kernels. The kernels could be made into a foodstuff which is eaten, and which would not need to be refrigerated.

a) Suggest and explain two advantages of the corn-based hepatitis B vaccine compared to a normal hepatitis B vaccine, particularly in developing countries where hepatitis B is common.

b) Suggest one concern people may have about growing these genetically engineered corn plants.

Exam Tip
If you're asked to 'suggest' an answer in the exam, you're not expected to already know the correct answer. You're expected to use your scientific knowledge to put forward a sensible idea.

4. Human Population Growth and GM Organisms

Scientists are looking at ways to provide enough food for the growing human population — this includes the use of GM (genetically modified) crops.

Learning Objectives:

- Be able to explain the advantages and disadvantages of genetic engineering to produce GM organisms including the modification of crop plants and the introduction of genes for insect resistance from *Bacillus thuringiensis* into crop plants.
- Be able to explain the advantages and disadvantages of agricultural solutions to the demands of a growing human population, including use of fertilisers and biological control.

Specification References 4.12B, 4.13B

Why use GM crops?

The world's population is rising very quickly — and it's not slowing down. This means that global food production must increase too so that we all have access to enough food that is safe for us to eat and has the right balance of nutrition — this is known as '**food security**' (see pages 296-297 for more). One way to increase food security may be through the use of GM crops. However, not everyone agrees that these are a good idea.

Benefits of genetically modifying crops

On the plus side, GM crops can increase the amount of food that a crop provides (its yield). For example, crops can be produced that are resistant to pests or are able to grow better in drought conditions.

WORKING SCIENTIFICALLY

GM crops could also be engineered to contain additional nutrients. This could help to combat certain deficiency diseases. These are common in developing countries where some people's diets may be lacking in nutrients.

Tip: A pest is any organism that damages crops (usually by eating them).

Example

Vitamin A deficiency is common in parts of Africa and SE Asia. A lack of vitamin A can lead to blindness. 'Golden rice' is rice that's been engineered to produce a chemical that's converted in the body into vitamin A.

Concerns about genetically modifying crops

- Many people argue that people go hungry because they can't afford to buy food, not because there isn't any food about. So they argue that you need to tackle poverty first.
- There are fears that countries may become dependent on companies who sell GM seeds.
- Sometimes, poor soil is the main reason why crops fail in a certain area, and even GM crops won't survive.
- There are concerns that the long term effects of exposure to GM crops on human health and the environment aren't yet known.

Bt crops

Bt stands for *Bacillus thuringiensis*. It is a type of bacterium which produces a toxin (poison) that kills many of the insect larvae that are harmful to crops. The gene for the Bt toxin can be inserted into crops, such as cotton and corn, which then produce the toxin in their stems and leaves — making them resistant to the insect pests. The toxin is specific to insect pests — it's harmless to humans, animals and other insects.

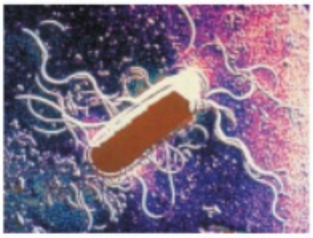


Figure 1: *A* Bacillus thuringiensis *bacterium.*

Figure 2: *Bt cotton being grown in the USA.*

Benefits and risks of Bt crops

Modifying crops to produce the Bt toxin can improve crop yield. Insects that eat the crop are killed by the toxin, so less of the crop gets eaten by pests and more food is produced for humans. It can also reduce the need for chemical pesticides, which may be harmful to the environment.

However, the insects that feed on the crops are constantly exposed to the toxin, so there's a danger they'll develop resistance and no longer be killed by it. Farmers try to avoid this happening by using other insecticides too.

Exam Tip
You need to be able to explain the advantages and disadvantages of genetically modifying crop plants, including Bt crop plants, for your exam.

Other methods of increasing food production

Using GM organisms is a relatively new way of improving crop yields. There are other, agricultural methods that can be used to increase food production and help feed the growing human population.

Fertilisers

If soils are poor, applying fertilisers is likely to be the best way to increase yields. Fertilisers contain minerals that are essential for plant growth, e.g. nitrates and phosphates. They replace the nutrients that have been lost from the soils to previous crops.

Tip: These methods could be used instead of GM crops or as well as GM crops.

However, excess fertilisers can cause problems in rivers and lakes through the process of **eutrophication** — an excess of nutrients in the water which leads to algal blooms and the death of aquatic organisms (see p.293).

Biological control

Biological control is an alternative method for controlling pest numbers to chemical pesticides or pest-resistant GM crops.

Biological control methods use other organisms (including predators and parasites) to reduce pest numbers.

Examples

- Cane toads (which are native to South and Central America, and the southern USA) were introduced into Australia to eat beetles that were damaging sugarcane crops.
- Parasitic wasps can be used to control aphid populations that feed on fruit crops. The wasps lay their eggs inside the aphids, which die when the larval wasps hatch out.

Biological control can have longer-lasting effects than chemical pesticides and be less harmful to wildlife. But introducing new organisms can cause problems.

Example

Cane toads are now a pest themselves in Australia because they poison the native predator species that eat them.

Practice Questions — Application

Q1 Aphids are a major pest of fruit crops. Ladybirds eat aphids. Ladybirds can be introduced into areas where fruit trees are growing in order to control aphid numbers.

a) What is the use of ladybirds to control aphid numbers an example of?

b) Suggest one possible problem with using the ladybirds in this way.

Q2 Fertilisers can be used to increase the level of nitrogen in nitrogen-poor soils.

a) Outline one problem that can be caused by the use of fertilisers.

b) A biotechnology firm creates a new GM crop that can grow well in nitrogen-poor soils.

Suggest one reason why a farmer may prefer to continue adding fertiliser to his soil, rather than switching to growing the new GM crop.

Q3 Bt potato plants have been genetically engineered to produce the *Bacillus thuringiensis* (Bt) toxin.

a) Explain a benefit of genetically engineering potato plants to produce the Bt toxin.

b) Suggest one possible risk of the widespread growth of potato plants that have been genetically engineered to produce the Bt toxin.

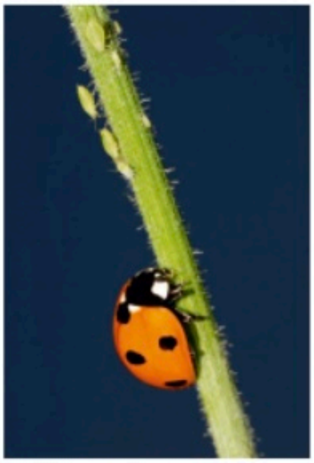


Figure 3: *A ladybird hunting aphids on a plant stem.*

Topic 4b Checklist — Make sure you know...

Selective Breeding

☐ That selective breeding involves humans selecting organisms to breed over several generations, so that a desirable characteristic gets stronger.

☐ That selective breeding has resulted in the edible crops and domesticated animals we have today.

☐ Some of the benefits and risks of selective breeding in agriculture and medicine, including ethical implications (e.g. the health problems caused by inbreeding in selectively bred animals) and practical implications (e.g. the risks associated with reducing the gene pool).

Tissue Culture

☐ The process of tissue culture in both plants and animals — including the use of a growth medium.

☐ That tissue culture can be used to produce whole plants quickly, cheaply and in very little space.

☐ That tissue culture can also be used to produce identical plants (clones) with desirable characteristics.

☐ That tissue culture can be used to produce animal cells and tissues for medical research, allowing scientists to study the cells in isolation, away from systems inside the body.

Genetic Engineering

☐ That during genetic engineering, a gene is transferred from one organism's genome into another organism's genome, in order to introduce a desirable characteristic.

☐ **H** The process of genetic engineering, including: the use of restriction enzymes to cut out the desired gene and cut open the vector DNA leaving unpaired bases (sticky ends), the use of ligase enzymes to join the gene to the vector DNA and the use of that vector (e.g. a plasmid or virus) to transfer the desired gene into other cells (e.g. bacteria).

☐ Some of the benefits and risks of genetic engineering in agriculture and medicine, including ethical implications (e.g. genetically engineered animals may suffer from health problems) and practical implications (e.g. genes from genetically engineered crops may get out into the environment).

Human Population Growth and GM Organisms

☐ That food production needs to increase to meet the demands of a growing human population and that one way this can be done is through the use of GM crops.

☐ Some of the advantages and disadvantages of using genetic engineering to produce GM crops, including those associated with the modification of crop plants for insect resistance using a gene from the bacterium *Bacillus thuringiensis*.

☐ That fertilisers can be used to increase food production by improving soil quality and crop growth, but can also cause environmental problems such as eutrophication.

☐ That biological control can be used to increase food production by reducing the damage caused by pests without the need for chemical pesticides, but that organisms used in biological control can also cause problems themselves.

Exam-style Questions

1 Tomato plants were among the first crop plants to be genetically engineered. Which of the following is an example of genetic engineering?

A Tomato plants being bred over several generations to produce large fruit.
B Tomato plants being cloned and grown on an artificial growth medium.
C A gene for disease resistance being transferred to tomato plants from another plant species.
D Tomato plants being grown without the use of chemical pesticides.

(1 mark)

2 A farmer is using selective breeding to try to produce a type of wheat that is resistant to a particular disease.

(a) (i) Suggest **one** benefit to the farmer of growing disease-resistant wheat.

(1 mark)

(ii) Suggest and explain **one** advantage to the farmer of using selective breeding to produce the wheat, rather than genetic engineering.

(2 marks)

(b) Describe how the farmer could produce disease-resistant wheat using selective breeding.

(4 marks)

(c) Suggest and explain **one** problem that could be caused by the selective breeding of wheat that is resistant to a particular disease.

(2 marks)

3 Factor VIII is a human protein which helps blood to clot. People with haemophilia A do not make enough functional factor VIII and their blood does not clot properly.

Non-human animal cells can be genetically engineered to produce human factor VIII. The cells can then be grown using tissue culture and the factor VIII harvested for the treatment of people with haemophilia A.

(a) Describe how non-human animal cells could be genetically engineered to produce human factor VIII.

(4 marks)

(b) Suggest **one** advantage of genetically engineering animal cells in isolation, over genetically engineering whole animals to produce the factor VIII protein.

(1 mark)

(c) Describe how large numbers of factor VIII-producing cells might be grown via tissue culture.

(3 marks)

1. Introduction to Health and Disease

Diseases are one cause of poor health. Sometimes, different diseases interact, leading to further health complications that don't appear related at first.

Learning Objectives:

- Be able to describe health as a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity, as defined by the World Health Organisation (WHO).
- Be able to describe the difference between communicable and non-communicable diseases.
- Be able to explain why the presence of one disease can lead to a higher susceptibility to other diseases.

Specification References
5.1, 5.2, 5.3

Diseases

A disease is a condition where part of an organism doesn't function properly. Diseases are often responsible for causing ill health, but being healthy is not just about being free from disease. The World Health Organisation (the WHO) has developed a definition for health:

> Health is a state of complete physical, mental and social well-being, and not merely the absence of disease or infirmity.

Tip: Infirmity means weakness or frailty.

Tip: The WHO definition of health means that even if someone is physically fit, they still might be unhealthy (e.g. they have mental health issues or are socially isolated).

Diseases can be communicable or non-communicable.

Communicable diseases

Communicable diseases are those that can spread between individuals. They are caused by things like bacteria, viruses, parasites and fungi. They're sometimes described as contagious or infectious diseases. Tuberculosis and malaria are examples of communicable diseases. There's more about communicable diseases on pages 153-157.

Non-Communicable diseases

Non-communicable diseases are those that can't spread between individuals. They generally last for a long time and get worse slowly. Asthma, cancer and coronary heart disease are examples of non-communicable diseases. See pages 187-189 for more on non-communicable diseases.

Susceptibility to other diseases

If you are affected by one disease, it could make you more susceptible to others — your body may become weakened by the disease, so it's less able to fight off others.

Tip: Being susceptible to a disease means that you have an increased chance of getting that particular disease.

Example

People who have problems with their immune system, e.g. AIDS patients (see p.157), have an increased chance of suffering from communicable diseases such as influenza (flu), because their body is less able to defend itself against the pathogen that causes flu.

Practice Questions — Fact Recall

Q1 What is meant by the term 'health'?

Q2 What is the main difference between communicable and non-communicable diseases?

2. Communicable Diseases

Disease isn't a particularly pleasant thing, but you've still got to learn about it. First up in the section is meeting the organisms that cause disease.

Pathogens

Pathogens are organisms that cause disease. They can cause **communicable (infectious) diseases** — diseases that can spread (see previous page). Both plants and animals can be infected by pathogens. There are several types of pathogen, including bacteria, viruses, protists and fungi.

Bacteria

Bacteria are very small cells, which can reproduce rapidly inside your body. They can make you feel ill by producing toxins (poisons) that damage your cells and tissues.

Example

Helicobacter pylori bacteria — these bacteria cause stomach ulcers (p.155).

Viruses

Viruses are not cells. Like bacteria, they can reproduce rapidly inside your body. They live inside your cells and replicate themselves using the cells' machinery to produce many copies of themselves. The cell will usually then burst, releasing all the new viruses (see page 158). This cell damage is what makes you feel ill.

Example

HIV (see page 157) — this virus infects and destroys cells that normally help to defend the body against disease (like white blood cells, see p.164-165).

Protists

There are lots of different types of protists. But they're all eukaryotes (see page 23) and most of them are single-celled. Some protists are parasites. Parasites live on or inside other organisms and can cause them damage. They are often transferred to the organism by a **vector**, which doesn't get the disease itself — e.g. an insect that carries the protist.

Example

Malaria is caused by a protist that lives inside a mosquito (p.156).

Fungi

Some fungi are single-celled. Others have a body which is made up of hyphae (thread-like structures). These hyphae can grow and penetrate human skin and the surface of plants, causing diseases. The hyphae can produce spores, which can be spread to other plants and animals.

Learning Objectives:

- Be able to describe a pathogen as a disease-causing organism, including bacteria, viruses, protists and fungi.
- Be able to describe how pathogens are spread and how this spread can be reduced or prevented, including: tuberculosis (airborne), cholera (water), stomach ulcers caused by *Helicobacter* (oral transmission), Ebola (body fluids), Chalara ash dieback (airborne) and malaria (animal vectors).
- Be able to describe some common bacterial infections, including: tuberculosis, cholera and stomach ulcers caused by *Helicobacter* bacteria.
- Be able to describe some common viral infections, including: Ebola and HIV.
- Be able to describe some common fungal infections, including Chalara ash dieback.
- Be able to describe some common protist infections, including malaria.
- Be able to explain how sexually transmitted infections (STIs) are spread and how this spread can be reduced or prevented, including the *Chlamydia* bacteria and the HIV virus.

Specification References
5.4-5.6, 5.8

Example

The ash dieback fungus infects ash trees — see pages 155-156 for more.

The spread of pathogens

Pathogens can be spread in many ways. Here are a few that you should know about.

- Some pathogens can be picked up by drinking or bathing in dirty water e.g. the bacterium that causes cholera.
- Pathogens can be airborne (carried in the air) and can then be breathed in, e.g. the bacterium that causes tuberculosis.
- Swallowing water or food contaminated with a pathogen can cause disease, e.g. the *Helicobacter* bacterium that causes stomach ulcers. The spread of disease in this way is known as **oral transmission**.
- Some pathogens can be picked up through infected bodily fluids. For example, the Ebola virus can be spread through coming into contact with the bodily fluids (such as blood, vomit, saliva and faeces) of somebody already infected with the disease.
- Some pathogens can be carried and transmitted by organisms known as animal **vectors**. For example, mosquitos are animal vectors which carry the protist that causes malaria.

Exam Tip
If you're asked in the exam to suggest how someone may have been infected with a disease, just use the information you've been given to work out whether it was likely to be via water, air, food, bodily fluids or by animal vectors.

Figure 1: *A microscopic image of an Ebola virus.*

Bacterial diseases

There are three examples of bacterial diseases that you need to know about.

Tuberculosis

Being exposed to the bacterium *Mycobacterium tuberculosis* can lead to an infection called tuberculosis (TB). Signs and symptoms of TB include coughing and lung damage.

The bacterium is spread through the air in droplets when infected individuals cough and sneeze. There are a variety of ways in which the spread of TB can be reduced.

Examples

- Infected individuals should avoid crowded public spaces and sleep alone.
- They should also practise good hygiene. This includes washing their hands regularly, covering their mouth and nose with tissues or a face mask when coughing or sneezing and disposing of tissues and face masks following use.
- A well ventilated home can also reduce the likelihood of transmission.

Exam Tip
How to prevent the spread of a disease is linked to how it spreads. For example, if a certain disease is transmitted via bodily fluids, then its spread can be prevented by avoiding contact with the bodily fluids of an infected individual.

Cholera

Cholera is a disease that is spread by the bacterium *Vibrio cholerae*. The main symptom of a cholera infection is diarrhoea that lasts for a few days. This can lead to severe dehydration and further complications, including death.

The pathogen spreads through contaminated water sources. Most cases of cholera occur in developing countries, where clean water is not widely available. The spread of cholera can be reduced by making sure that people have access to clean water supplies.

Stomach ulcers

The bacterium *Helicobacter pylori* can cause an infected individual to develop stomach ulcers. The bacteria can cause inflammation of the stomach lining, which can lead to the lining becoming damaged. This allows the stomach acid to penetrate the lining, creating a hole (known as an ulcer) that exposes the tissue underneath. Symptoms of stomach ulcers include stomach pain, nausea and vomiting.

Helicobacter pylori is spread mainly through oral transmission (see previous page), so transmission of the pathogen may be reduced by having clean water supplies and making sure that living conditions are hygienic, e.g. by disinfecting food preparation areas to help prevent contamination of food with the bacteria.

Tip: Stomach ulcers can also be caused by long-term use of certain medications, but you only need to know about ulcers caused by *Helicobacter*.

Viral diseases

You need to know about the viral infections Ebola and HIV (covered on page 157).

Ebola

Ebola is a virus that is spread through coming into contact with the bodily fluids of an infected individual. The virus causes haemorrhagic fever (a fever where you bleed internally or from your eyes, nose or mouth).

The spread of Ebola can be reduced by isolating infected individuals and sterilising any areas where the virus may be present, such as a hospital bed used by somebody infected with the virus. The spread of the virus can also be reduced by ensuring that medical staff regularly wash their hands and wear protective clothing (see Figure 2).

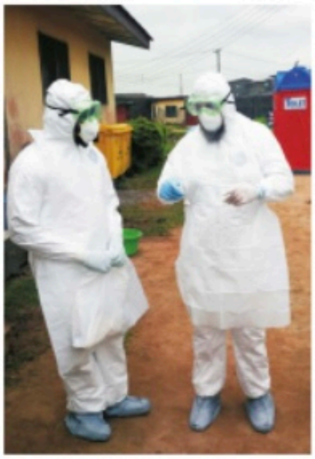


Figure 2: *Medical staff dressed in protective clothing whilst treating Ebola patients.*

Fungal and protist diseases

You also need to know about some diseases caused by fungi and protists.

Chalara ash dieback

A fungus is responsible for the disease known as Chalara ash dieback. The fungus infects ash trees, with symptoms including loss of leaves and bark lesions (wounds). In most cases it leads to the death of the entire tree, either directly or by weakening the tree to a point where it cannot defend itself from other diseases (p.160).

The fungus is carried through the air by the wind. It can also spread when ash trees already infected with the disease are moved between different areas.

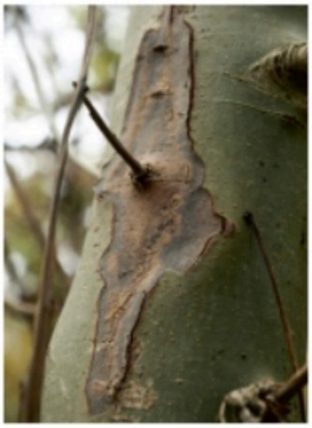


Figure 3: A lesion on the trunk of an ash tree caused by the fungal disease Chalara ash dieback.

There are two main strategies for slowing down the spread of the disease.

- Removing young, infected ash trees and replanting with a different species of tree (e.g. birch) can slow down the spread of the fungus.
- Efforts have also been made to reduce the spread of the disease by placing restrictions on the import and movement of ash trees.

Malaria

Malaria is caused by a protist. Part of the malarial protist's life cycle takes place inside the mosquito. The mosquitoes are vectors — they pick up the malarial protist when they feed on an infected animal, but don't get the disease themselves. Every time the mosquito feeds on another animal, it infects it by inserting the protist into the animal's blood vessels.

Malaria causes repeating episodes of fever. It can be fatal. It also causes damage to red blood cells and, in severe cases, to the liver. The spread of malaria can be reduced by stopping the mosquitoes from breeding.

Example

Mosquitoes can breed in standing water, so mosquitoes can be prevented from breeding by removing these water sources. For example, people who live in areas with a risk of malaria should make sure that they empty or get rid of any containers on their land that fill with rainwater.

Figure 4: A mosquito net hangs over a bed.

People can also be protected from mosquito bites to stop the spread of the disease.

Examples

- Spraying any exposed skin with an insect repellant can prevent people from being bitten by mosquitoes.
- Sleeping under a mosquito net can prevent people from being bitten when they're asleep.

Sexually transmitted infections

Sexually transmitted infections (STIs) are spread through sexual contact, including sexual intercourse. They can be caused by a bacteria, virus, fungus or protist. There are two STIs that you need to know about.

Chlamydia

Chlamydia is a kind of bacterium, but it behaves in a similar way to a virus because it can only reproduce inside host cells (see p.158 for more on viruses).

Although it doesn't usually cause symptoms, it can result in infertility in men and women. In some cases, *Chlamydia* can be passed on from an infected woman to her child during childbirth.

The spread of *Chlamydia* can be reduced by wearing a condom when having sex or avoiding sexual contact. Since the disease doesn't often cause any symptoms, screening is available to help with early detection. Once the infection is diagnosed, the individual can be treated. This reduces the time that they could unknowingly pass the infection on to other individuals.

Tip: Some STIs, including chlamydia, are spread by genital contact, not just sexual intercourse.

Tip: *Chlamydia* bacteria cause the disease chlamydia.

Tip: Condoms are the only type of contraception that protects against STIs.

HIV

HIV is the Human Immunodeficiency Virus. It attacks white blood cells, which are a key part of the body's immune response (see pages 164-165). Following infection with HIV, some people experience flu-like symptoms, whereas others may not experience any symptoms at all. Usually, the person doesn't then experience any symptoms for several years. During this time, HIV can be controlled with antiretroviral drugs, which stop the virus replicating in the body.

Over time, HIV will destroy enough white blood cells that the infection leads to **AIDS** (Acquired Immune Deficiency Syndrome). This is when the infected person's immune system deteriorates and eventually fails. Because of this, the person becomes very vulnerable to opportunistic infections by other pathogens that the body would normally be able to fight off.

HIV is spread by exchanging certain infected bodily fluids (e.g. blood, semen, vaginal fluids). This most commonly occurs through sexual intercourse and by sharing needles when taking drugs. This means that the spread of HIV can be greatly reduced by using a condom when having sex and by drug users not sharing needles. Medication can reduce the risk of an infected individual passing the virus on to others during sex (or of a mother passing the virus to her baby during pregnancy) so screening and proper treatment are also important.

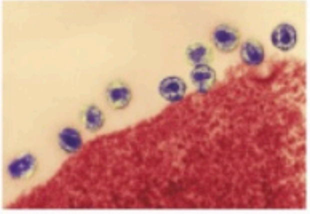


Figure 5: *HIV particles (blue) infecting a white blood cell.*

Tip: Opportunistic infections are caused by pathogens that take advantage of a weakened or impaired immune system.

Practice Questions — Fact Recall

Q1 a) List two signs or symptoms of tuberculosis.

b) Describe how *Mycobacterium tuberculosis* is spread.

Q2 How can the spread of cholera be reduced?

Q3 Describe the signs that suggest that a person who is infected with *Helicobacter pylori* has developed a stomach ulcer.

Q4 a) Name a type of plant that can be infected by the Chalara fungus.

b) Give two symptoms seen in a plant infected with the Chalara fungus.

Q5 Why are mosquito nets used in areas with a high risk of malaria?

Q6 Describe what is meant by the term 'sexually transmitted infection'.

Q7 Give two ways in which the spread of *Chlamydia* can be reduced.

Q8 Describe how HIV affects the body.

Practice Questions — Application

Q1 A patient in a hospital has the Ebola virus and has been put into isolation. Suggest why they have been put into isolation, with reference to how the virus is spread.

Q2 A nurse working in a GP surgery washes his hands carefully after seeing patients. Suggest how this will prevent the spread of disease.

Learning Objective:

- Be able to describe the life cycle of a virus, including the lysogenic and lytic pathways.

Specification Reference 5.7B

3. Virus Reproduction

Viruses can't live on their own — they need infect a living cell to reproduce in. Once they get inside, they hijack the cell and force it to make copies of them...

The life cycle of a virus

Viruses aren't cells. They're usually no more than a protein coat around a strand of genetic material — see Figure 1.

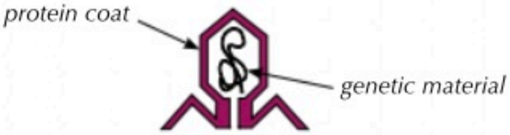


Figure 1: *A typical virus.*

Viruses have to infect living cells (called host cells) in order to reproduce. Specific types of virus will only infect specific cells. The life cycle of a virus starts with when it infects a new host cell. There are two pathways that a virus can reproduce through — the **lytic pathway** and the **lysogenic pathway**. Many viruses reproduce by the lytic pathway, but some enter the lysogenic pathway first.

The lytic pathway

1. The virus attaches itself to a specific host cell and injects its genetic material into the cell.
2. The virus then uses proteins and enzymes in the host cell to replicate its genetic material and produce the components of new viruses.
3. Once all the viral components are produced, they assemble and form new viruses.
4. The host cell splits open, releasing the new viruses. These new viruses can go on to infect more cells.

The lysogenic pathway

1. The virus attaches itself to a specific host cell and injects its genetic material into the cell.
2. The genetic material injected by the virus is incorporated into the genome (DNA) of the host cell.
3. The viral genetic material gets replicated along with the host DNA every time the host cell divides. At this point, the virus is dormant (inactive) and no new viruses are made.
4. Eventually a trigger (e.g. the presence of a chemical) causes the viral genetic material to leave the genome and enter the lytic pathway.

Both pathways are summarised in Figure 2 on the next page.

Tip: Make sure you know which pathway is which. Remember, the lysogenic pathway incorporates the viral genetic material into the host's genome.

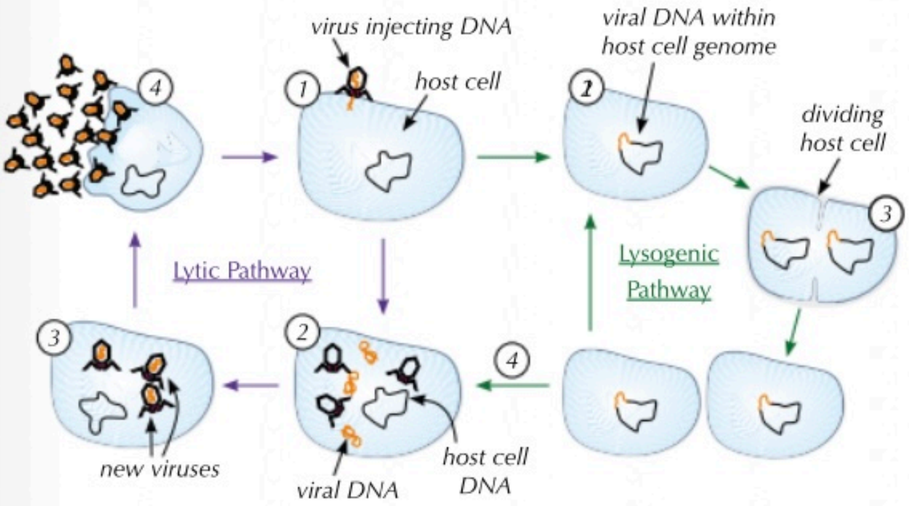

virus injecting DNA
host cell
viral DNA within host cell genome
dividing host cell
④
①
②
③
Lytic Pathway
Lysogenic Pathway
③
②
④
new viruses
viral DNA
host cell DNA

Figure 2: *The lytic and lysogenic pathways of the reproductive life cycle of a virus.*

Tip: The lytic pathway can happen over a few minutes, but a virus can stay in the lysogenic pathway for many years.

Practice Questions — Fact Recall

Q1 Describe what happens during the lytic pathway.

Q2 Describe how a virus would enter the lytic pathway from the lysogenic pathway.

Practice Question — Application

Q1 The T4 phage is a type of virus that infects *E. coli* bacteria. After the virus replicates, the bacterial cell bursts open. Name the pathway used by the T4 phage to replicate.

Learning Objectives:

- Be able to describe how some plants defend themselves against attack from pests and pathogens by physical barriers, including the leaf cuticle and cell wall.
- Be able to describe how plants defend themselves against attack from pests and pathogens by producing chemicals, some of which can be used to treat human diseases or relieve symptoms.
- **H** Be able to describe different ways plant diseases can be detected and identified in the lab and in the field, including the elimination of possible environmental causes, distribution analysis of affected plants, observation of visible symptoms and diagnostic testing to identify pathogens.

Specification References 5.9B-5.11B

Exam Tip
You don't need to remember specific examples of plants that produce antiseptics and poisons, just that they are able to do so.

4. Plant Diseases

Plants aren't just affected by diseases — they can also be up against pests who either want to eat them or live on them. Luckily, they have some defences.

Plant defences

Plants have physical and chemical defences against pests (insects and other animals that eat or damage plants) and pathogens (see p.153).

Physical defences

Most plant leaves and stems have a waxy cuticle, which provides a barrier to stop pathogens entering or pests from damaging them. The waxy cuticle may also stop water collecting on the leaf, which could reduce the risk of infection by pathogens that are transferred in water.

Plant cells are surrounded by cell walls made from cellulose. These form a physical barrier against pathogens that make it past the waxy cuticle.

Chemical defences

Plants also produce chemicals that help to prevent damage to the plant by pests and pathogens. Some plants can produce chemicals called **antiseptics** which kill bacterial and fungal pathogens.

Example

Spearmint plants produce an oil that acts as a natural fungicide (a substance that kills fungus).

Other plants produce poisons which can deter pests (e.g. insects) from feeding on their leaves.

Examples

- The nicotine produced by tobacco plants acts as an insecticide.
- Foxgloves contain a poison called digoxin which can be toxic if consumed in sufficient quantities.

Some of these chemicals can be used as drugs to treat human diseases or relieve the symptoms of diseases.

Examples

- Quinine comes from the bark of the cinchona tree.
  For years it was the main treatment for malaria.
- Aspirin is used to relieve pain and fever. It was developed from a chemical found in the bark and leaves of willow trees.

These defences help protect plants from infection. However, sometimes pathogens make it past these defences and cause disease.

Detecting plant diseases Higher

Plant diseases can be detected in both the field and the lab.

In the field

In the field, plant diseases are usually detected by observations. Plant pathologists examine plants and recognise symptoms of disease.

Tip: H A plant pathologist is a scientist who is an expert in the study of plant disease.

Example **Higher**

Galls (abnormal growths) might indicate crown gall disease in many different types of plant, including apple and other fruit trees — see Figure 1.

Sometimes plants may show symptoms of a disease (e.g. yellow leaves) which are actually due to environmental causes, such as a nutrient deficiency. By changing the environmental conditions, such as adding nutrients to the soil, and observing any change in the plant's symptoms, it can be determined whether a plant is diseased or if the symptoms are due to something else.

Different pathogens spread in different ways, so plant pathologists can analyse the distribution of diseased plants to identify the kind of pathogen involved. For example, patches of diseased plants may suggest that the disease is spread through the soil and a random distribution may suggest an airborne pathogen.

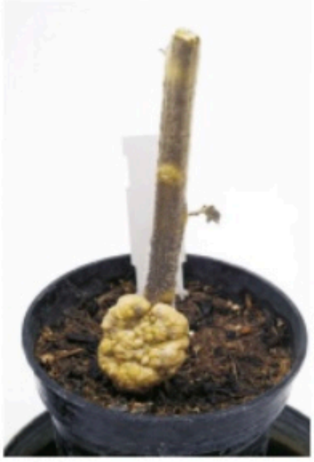


***Figure 1:** A tomato plant affected by crown gall disease. It has a growth at the bottom of the stem.*

In the lab

Pathogens have unique molecules on their surface called antigens. Antigens from a particular pathogen will be found in a plant infected with that pathogen, and can be detected in a sample of plant tissue using monoclonal antibodies (proteins made to bind to a specific antigen, see p.169). The detection of an antigen unique to a particular pathogen allows that pathogen to be identified and the disease diagnosed.

If a plant is infected with a pathogen, the pathogen's DNA will be present in the plant's tissues. Scientists have techniques that allow them to detect even small amounts of pathogen DNA in a sample of plant tissue, allowing them to identify the particular pathogen that is present.

Tip: H Lab-based diagnostic testing allows accurate identification of specific pathogens, whereas field-based testing is a bit more rough-and-ready.

Practice Questions — Fact Recall

Q1 Describe two physical defences that plants have against pathogens.

Q2 Describe how a scientist might detect diseased plants in the field.

Practice Question — Application

Q1 Some tomato plants in a field are starting to develop yellow leaves. Suggest how a plant pathologist could determine whether the symptoms are caused by:

a) a deficiency in nitrogen.

b) a fungus.

Topic 5a Checklist — Make sure you know...

Introduction to Health and Disease

☐ That health is the state of complete physical, mental and social wellbeing and that simply being free from disease does not necessarily make an individual healthy.

☐ That diseases can be communicable or non-communicable, and what is meant by these terms.

☐ That the presence of one disease can increase the likelihood of an individual catching other diseases.

Communicable Diseases

☐ That pathogens are organisms that cause disease, and include bacteria, viruses, protists and fungi.

☐ That tuberculosis is an airborne bacterial disease that causes lung damage, and its spread can be reduced in ways such as practising good hygiene and ensuring patients avoid public spaces.

☐ That cholera is a bacterial disease that causes diarrhoea and spreads via contaminated drinking water, and that transmission of cholera can be prevented by having clean water supplies.

☐ That stomach ulcers can be caused by *Helicobacter* bacteria that spread mainly through oral transmission, and that transmission of the bacteria can be reduced by having hygienic living conditions and clean water supplies.

☐ That the Ebola virus causes haemorrhagic fever and is spread through bodily fluids, and that the spread can be reduced by sterilising infected areas and isolating infected people.

☐ That Chalara ash dieback is an airborne fungal disease that causes leaf loss and bark lesions in ash trees, and that the spread of the fungus can be reduced by replacing infected trees with a different species and placing restrictions on the import and movement of ash trees.

☐ That malaria is a disease caused by a protist that causes damage to red blood cells and the liver, and that it's spread via animal vectors (mosquitoes) can be reduced by preventing mosquitoes from breeding and by taking precautions to avoid being bitten (e.g. mosquito nets).

☐ That the sexually transmitted infection chlamydia (caused by *Chlamydia* bacteria) is spread through sexual contact, and that transmission can be reduced by wearing a condom when having sex or avoiding sexual contact, and screening individuals so they can be treated for the infection.

☐ That the HIV virus destroys the white blood cells of the immune system, leading to the onset of AIDS.

☐ That HIV is the spread through the exchange of certain bodily fluids, often during sex, and that its spread can be reduced by wearing a condom when having sex, screening and taking medication.

Virus Reproduction

☐ How viruses reproduce in the cells of a host organism through the lytic and lysogenic pathways.

Plant Diseases and Defences

☐ That plants have physical defences (including the leaf cuticle and cell walls) and chemical defences against pathogens and pests.

☐ That plants produce chemicals which can be used to treat human diseases and their symptoms.

☐ **H** How plant diseases can be detected and identified in the field and in the laboratory.

Exam-style Questions

1 A patient in a hospital has been diagnosed with malaria after returning from Kenya.

(a) Give **one** effect that malaria has on the body.

(1 mark)

(b) (i) Name the type of pathogen that causes malaria.

(1 mark)

(ii) Suggest **two** ways in which the spread of the pathogen can be reduced.

(2 marks)

(c) The patient is treated and is declared fit to go home, as the pathogen has been eradicated and he is free from disease. Suggest why, despite being disease-free, the patient may not necessarily be healthy.

(1 mark)

2 A garden centre has to keep its plants healthy and free from disease.

(a) (i) Some of the plants can produce chemicals which help to defend themselves from pests and pathogens. Describe **two** types of chemical defence that these plants may have.

(2 marks)

(ii) How might the chemicals produced by these plants be useful to humans?

(1 mark)

The staff discover that a young ash tree has been infected with Chalara ash dieback.

(b) What type of pathogen causes Chalara ash dieback?

(1 mark)

(c) Suggest **one** way that the ash tree may have been infected.

(1 mark)

3 HIV is a virus that kills white blood cells in the body.

(a) (i) Describe how HIV is spread between humans.

(1 mark)

(ii) Suggest **two** ways in which the spread of HIV can be reduced.

(2 marks)

(b) (i) Viruses can only reproduce by infecting living cells.
What is the name given to the cell that a virus infects?

(1 mark)

(ii) Many viruses enter the lytic pathway, but some will go by the lysogenic pathway first. Describe the lysogenic pathway, and how it is related to the lytic pathway.

(3 marks)

1. Defences Against Disease

Learning Objectives:

- Be able to describe how the physical barriers of the human body provide protection from pathogens, including skin, mucus and cilia.
- Be able to describe how the chemical defences of the human body provide protection from pathogens, including hydrochloric acid and lysozymes.
- Be able to explain the role of the specific immune system of the human body in defence against disease, including exposure to the pathogen, and the role of antigens in triggering an immune response which causes the production of antibodies.

Specification References
5.12, 5.13

Part of being healthy means being free from disease.
But that's easier said than done...

The body's defences

In order to cause disease, pathogens (disease causing organisms — see p.153) first need to enter the body. Like plants (see p.160), the human body has got features that stop a lot of nasties getting inside in the first place. These features are known as 'barriers' and are the body's first line of defence against disease. They are non-specific, which means that they work against many different types of pathogen. There are two types of barrier that you need to know about — physical barriers and chemical barriers.

Physical barriers

Physical barriers act to block the entrance of pathogens into the body.

Examples

- The skin acts as a barrier to pathogens. If it gets damaged, blood clots can quickly seal any cuts to help keep microorganisms out of the body.
- Hairs and mucus in your nose trap particles that could contain pathogens.
- Some cells in the trachea and bronchi (airways in the lungs) secrete mucus to trap pathogens.
- Other cells that line the trachea and bronchi have cilia. These are hair-like structures, which waft the mucus up to the back of the throat where it can be swallowed.

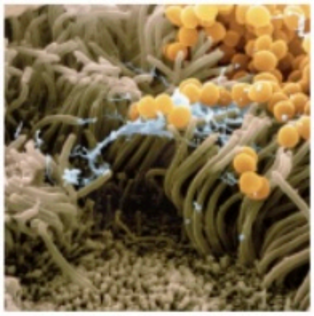


Figure 1: *Bacteria (yellow) sticking to mucus (blue) on microscopic hairs in the nose.*

Chemical barriers

The body produces a variety of chemicals which can destroy pathogens. These are known as chemical barriers.

Examples

- The stomach produces hydrochloric acid. This kills pathogens that make it that far from the mouth.
- The body produces enzymes called lysozymes that can kill bacteria. Lysozymes are present in several substances secreted by the body, such as in tears where they kill bacteria on the surface of the eye.

The immune system

If pathogens do make it into your body, your immune system kicks in to destroy them. The most important part of your immune system is the **white blood cells**. They travel around in your blood and crawl into every part of you, constantly patrolling for pathogens.

When white blood cells come across an invading pathogen, they can respond in different ways, for example:

1. Consuming them

Some white blood cells can engulf foreign cells and digest them. This is called **phagocytosis**. It's a non-specific response.

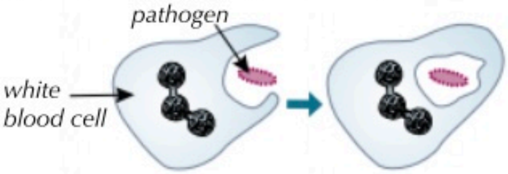


Figure 2: *A white blood cell engulfing a pathogen.*

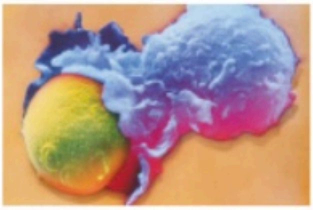


Figure 3: *A white blood cell (blue/pink) engulfing a pathogen (yellow/green). Seen under a microscope.*

2. Producing antibodies

B-lymphocytes are a type of white blood cell that are involved in the specific immune response — this is the immune response to a specific pathogen.

Every invading pathogen has unique molecules (e.g. proteins) called **antigens** on its surface. When your B-lymphocytes come across an antigen on a pathogen, they will start to produce proteins called **antibodies.** These antibodies bind (lock on) to the invading cells so that they can be found and destroyed by other white blood cells.

Tip: Antigens found on the surface of pathogens can be described as 'foreign' — they're not recognised by the B-lymphocytes.

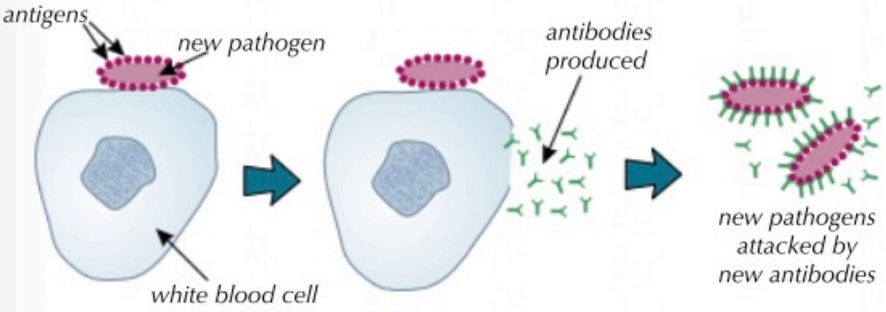


Figure 4: *Diagram showing the production of antibodies.*

Tip: Memory lymphocytes are also produced after an immune response to an antigen (see next page for more).

The antibodies produced are specific to that type of pathogen — they won't lock on to any others. Antibodies are then produced rapidly and carried around the body to find all similar pathogens.

Exam Tip
Don't get antigens and antibodies mixed up in the exam. Remember, the body makes antibodies against the antigens on pathogens.

Practice Questions — Fact Recall

Q1 Give three physical barriers to disease.

Q2 Give two ways in which white blood cells help to defend the body against disease.

Practice Question — Application

Q1 The SARS coronavirus (SARS-CoV) causes SARS, a respiratory disease. It can enter the body by being inhaled in droplets. Describe one feature of the body that helps to protect the body from infection with SARS-CoV.

Exam Tip
In the exam, you might get asked questions about pathogens or diseases you've never heard of before. Don't let that put you off though — you should be able to work out the answers by applying what you already know.

Learning Objectives:

- Be able to explain the role of the specific immune system of the human body in defence against disease, including how antigens trigger the production of memory lymphocytes, and the role of memory lymphocytes in the secondary response to the antigen.
- Be able to explain the body's response to immunisation using an inactive form of a pathogen.

Specification References
5.13, 5.14

2. Memory Lymphocytes and Immunisation

Our immune system contains special cells which can remember what pathogens have invaded our bodies in the past. This means our bodies can respond faster if they invade again...

Memory lymphocytes

When a pathogen enters the body for the first time, the response of the immune system is slow. This is because there aren't many B-lymphocytes that can make the antibody needed to bind with the new antigen. Eventually the body will produce enough of the right antibody to overcome the infection. During this time, the infected person will show symptoms of the disease.

As well as antibodies, special white blood cells called **memory lymphocytes** are produced in response to a foreign antigen. Memory lymphocytes remain in the body for a long time, and can 'remember' a specific antigen. The person is now **immune** to the pathogen, as their immune system has the ability to respond quickly to a second infection. If the same pathogen enters the body again, there are more cells that will recognise it and produce antibodies against it.

This secondary immune response is faster and stronger than the primary response which occurred when the body was first exposed to the new pathogen. The secondary response often gets rid of the pathogen before you begin to show any symptoms (see Figure 1).

Tip: The secondary response is always faster than the primary response. This is shown by a steeper line in graphs of blood antibody concentration against time.

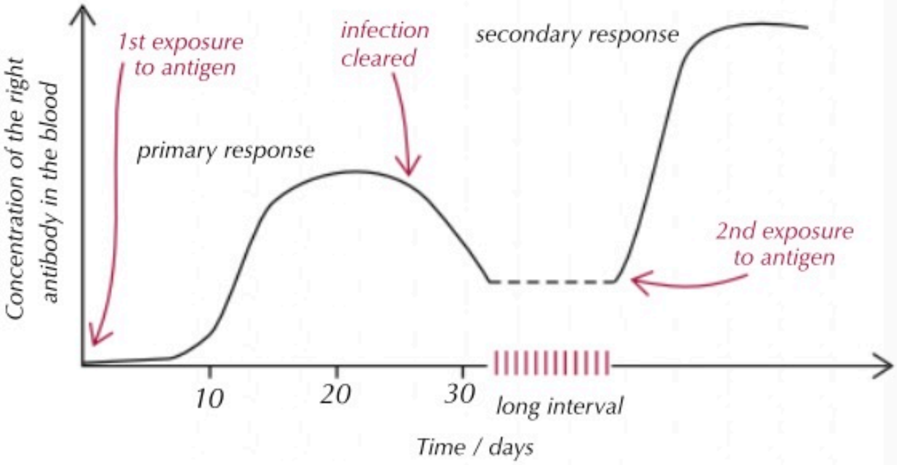


Figure 1: *A graph of antibody concentration against time since antigen exposure.*

Immunisation

When you're infected with a new pathogen, it takes your white blood cells a few days to learn how to deal with it. But by that time, you can be pretty ill. You can be immunised against some diseases (e.g. measles), which can stop you getting ill in the first place.

Immunisation usually involves injecting a vaccine into the body which contains small amounts of dead or inactive pathogens.

The pathogens are antigenic (they carry antigens). This causes your white blood cells to produce antibodies to target them — even though the pathogens are harmless (because they're dead or inactive).

Example

Children can be immunised against measles, mumps and rubella using the MMR vaccine. It contains weakened versions of the viruses that cause these diseases, all in one vaccine.

Tip: A vaccination is when you give someone a vaccine. It's a method of immunisation.

Figure 2: *A baby being given the MMR vaccine.*

The antigens will also trigger the production of memory lymphocytes (see previous page). So, if live pathogens of the same type then get into the body at a later date, the memory lymphocytes can rapidly mass-produce antibodies to help destroy the pathogen in a secondary immune response. This means the person is less likely to get ill (see Figure 3).

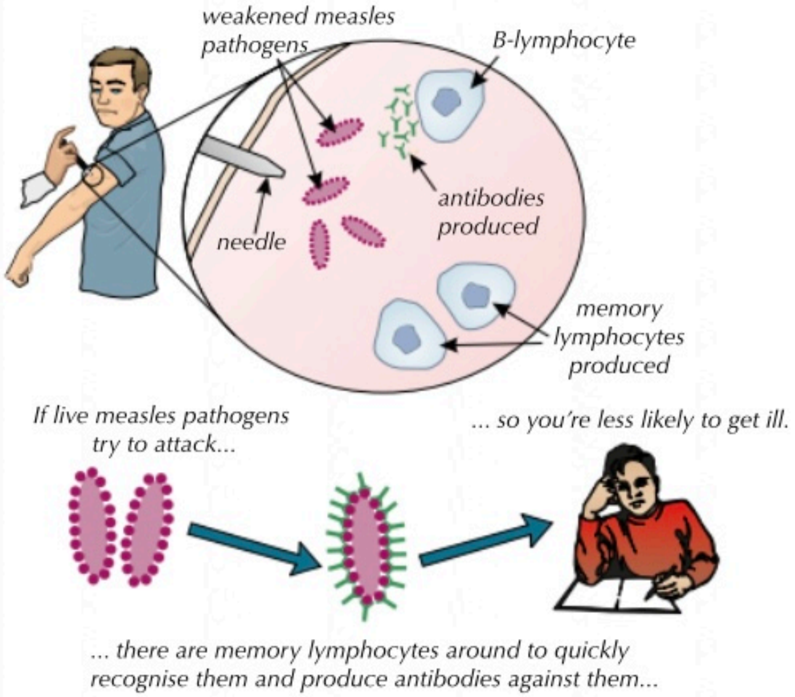

weakened measles pathogens
B-lymphocyte
needle
antibodies produced
memory lymphocytes produced
If live measles pathogens try to attack...
... so you're less likely to get ill.
... there are memory lymphocytes around to quickly recognise them and produce antibodies against them...

Figure 3: *A diagram of how immunisation works.*

Tip: Remember, antibodies are specific to a particular type of pathogen (see p.165). So a vaccination against the typhoid bacterium will only protect you against typhoid — it won't make you immune to anything else.

Practice Questions — Application

Q1 Whooping cough is a severe cough that can cause serious breathing difficulties in young babies.
Suggest how a whooping cough vaccination might work.

Q2 A child was exposed to the virus that causes chickenpox, and developed symptoms of the disease. Six months later, the child was exposed to the same virus but did not develop any symptoms. Explain why.

Tip: Don't get white blood cells confused with red blood cells. Red blood cells transport oxygen around the body, whilst white blood cells are part of the immune system.

3. Pros and Cons of Immunisation

Immunisation is a key component of modern healthcare. But, as with most things, it has advantages and disadvantages...

Immunisation — pros and cons

There are both pros and cons of immunisation.

Pros

- Immunisation programmes have helped control lots of infectious diseases that were once common in the UK (e.g. polio, measles, whooping cough, rubella, mumps, tetanus...). Smallpox no longer occurs at all, and polio infections have fallen by 99%.
- Big outbreaks of disease — called **epidemics** — can be prevented if a large percentage of the population are immunised. That way, even the people who aren't immunised are unlikely to catch the disease as there are fewer people able to pass it on. This is known as "**herd immunity**". But if a significant number of people aren't immunised, the disease can spread quickly and many people will be ill at the same time.

Cons

- Immunisation programmes don't always work — vaccines don't always give you immunity.
- You can sometimes have a bad reaction to a vaccine (e.g. swelling, or maybe something more serious like a fever or seizures). But bad reactions are very rare.

Balancing the risks

Deciding whether to have a vaccination means balancing risks — the risk of catching the disease if you don't have a vaccine, against the risk of having a bad reaction if you do. As always, you need to look at the evidence.

Example

If you get measles (the disease), there's about a 1 in 15 chance that you'll get complications (e.g. pneumonia) — and about 1 in 500 people who get measles actually die. However, the number of people who have a problem with the vaccine is more like 1 in 1 000 000.

Practice Question — Application

Q1 In 2012, the US state of Washington declared a whooping cough epidemic. The Department of Health encouraged all adults to get booster immunisations against the disease, to help protect babies who were too young to receive the immunisation.

Explain how a large-scale immunisation of adults could help to protect babies who haven't been immunised.

Learning Objective:

- Be able to discuss the advantages and disadvantages of immunisation, including the concept of herd immunity.

Specification Reference 5.15B

Tip: Herd immunity is important for helping to protect people who can't be vaccinated. E.g. those who are too young or too ill, or people who have problems with their immune system.

Tip: Herd immunity does not help protect against non-communicable diseases. For example, there is a vaccine for tetanus, but the disease is not contagious. So even if a large proportion of the population is immunised against tetanus, the unimmunised population will remain unprotected.

Exam Tip

In the exam, you might get asked to 'evaluate' the pros and cons of immunisation. This means giving a balanced account of both the advantages and the disadvantages, before trying to come up with an overall judgement.

Tip: Some immunisations "wear off" over time. So booster injections may need to be given to increase levels of antibodies again.

4. Monoclonal Antibodies Higher

Scientists can mass-produce antibodies for all sorts of uses. They're called monoclonal antibodies, and can be engineered to bind to anything you want.

Producing monoclonal antibodies

Antibodies are produced by B-lymphocytes — a type of white blood cell (see page 165). **Monoclonal antibodies** are produced from lots of clones of a single B-lymphocyte. This means all the antibodies are identical and will only target one specific protein antigen. However, you can't just grab the lymphocyte that made the antibody and grow more — lymphocytes don't divide very easily. Tumour cells, on the other hand, don't produce antibodies but divide lots — so they can be grown really easily. It's possible to fuse a mouse B-lymphocyte with a type of tumour cell called a myeloma cell, to create a cell called a **hybridoma**. Hybridoma cells can be cloned to get lots of identical cells. These cells can all divide really quickly to produce the same antibodies (monoclonal antibodies). The antibodies can be collected and purified.

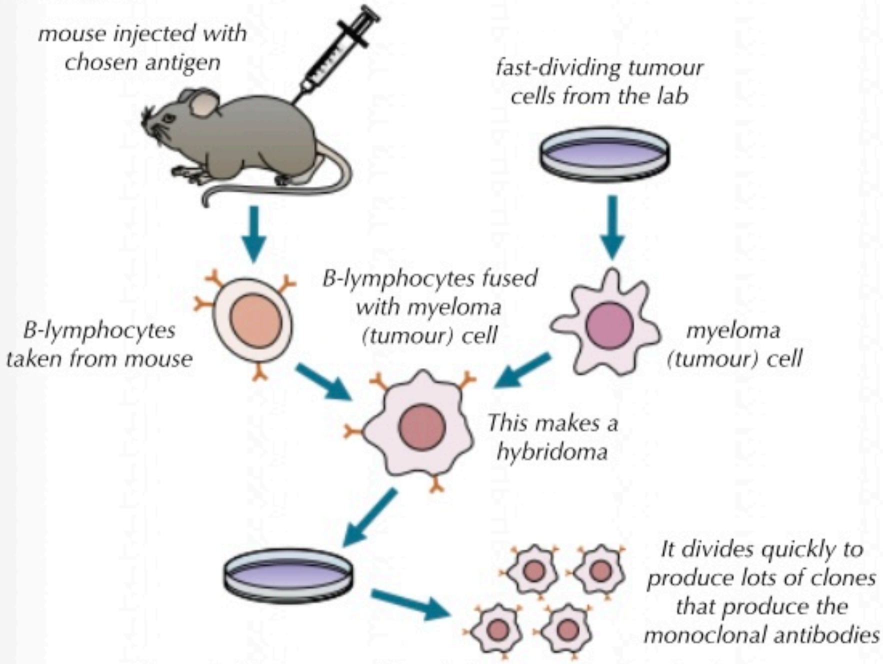

mouse injected with chosen antigen
fast-dividing tumour cells from the lab
B-lymphocytes taken from mouse
B-lymphocytes fused with myeloma (tumour) cell
myeloma (tumour) cell
This makes a hybridoma
It divides quickly to produce lots of clones that produce the monoclonal antibodies

Figure 1: *The process of producing monoclonal antibodies.*

You can make monoclonal antibodies that bind to anything you want, e.g. an antigen that's only found on the surface of one type of cell. Monoclonal antibodies are really useful because they will only bind to (target) this molecule. This means you can use them to target a specific cell or chemical in the body.

Practice Questions — Fact Recall

Q1 What two things are fused to make a hybridoma cell?

Q2 What happens in monoclonal antibody production after a hybridoma cell has been made?

Learning Objective:

- H Be able to describe the production of monoclonal antibodies, including:
  - H the use of lymphocytes which produce desired antibodies but do not divide;
  - H the production of hybridoma cells;
  - H that hybridoma cells produce antibodies as they divide.

Specification Reference 5.21B

Tip: H Injecting the mouse with an antigen stimulates the production of antibodies against the antigen.

Tip: H A B-lymphocyte is just one type of lymphocyte.

Exam Tip H

Make sure you know the process of producing monoclonal antibodies inside-out — you could be asked to describe it in the exam.

5. Monoclonal Antibody Uses Higher

Learning Objectives:

- H Be able to explain the use of monoclonal antibodies in pregnancy testing.
- H Be able to explain the use of monoclonal antibodies in diagnosis, including locating the position of cancer cells and blood clots and in the treatment of diseases, including cancer.
- H Be able to explain the advantages of using of monoclonal antibodies to target specific cells compared to drug and radiotherapy treatments.

Specification Reference 5.22B

With their ability to bind to a specific chemical or pathogen, monoclonal antibodies are useful for lots of things. These pages just cover a few of the things they're used for — read on to find out...

Pregnancy tests

Monoclonal antibodies can be used to diagnose diseases and other health conditions. For example, monoclonal antibodies are used in pregnancy tests. A hormone called HCG is found in the urine of women only when they are pregnant. Pregnancy testing sticks use monoclonal antibodies to detect this hormone.

Here's how they work:

The test stick

The bit of the stick you wee on has some antibodies to the hormone, with blue beads attached. The test strip (the bit of the stick that turns blue if you're pregnant) has some more antibodies to the hormone stuck onto it (so that they can't move).

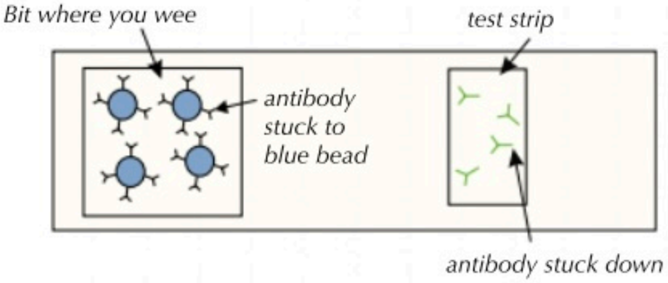


Figure 1: *Diagram showing a pregnancy test before being used.*

Tip: H By using different antibodies, you can use this test to find other substances in a sample of urine, e.g. antigens on pathogens.

If you're pregnant

If you're pregnant and you wee on the stick, the hormone binds to the antibodies on the blue beads. The urine moves up the stick, carrying the hormone and the beads. The beads and hormone bind to the antibodies on the strip. So the blue beads get stuck on the strip, turning it blue.

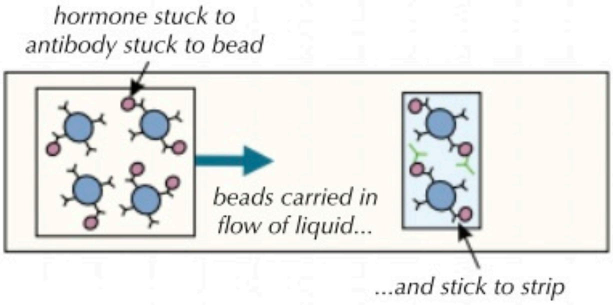

hormone stuck to antibody stuck to bead
beads carried in flow of liquid...
...and stick to strip

Figure 3: *Diagram showing a positive pregnancy test.*

Figure 2: *A pregnancy test. The left end is where urine is applied. The window halfway along shows the test strip and the control strip (see next page).*

If you're not pregnant

If you're not pregnant and you wee on the stick, the urine still moves up the stick, carrying the blue beads. But there's nothing to stick the blue beads onto the test strip (the HCG hormone isn't present), so it doesn't go blue.

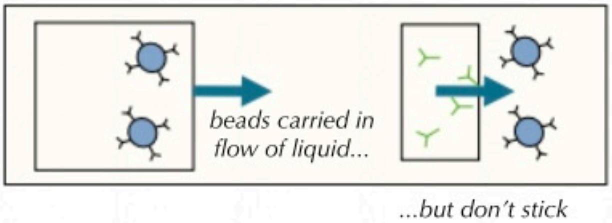


Figure 4: *Diagram showing a negative pregnancy test.*

Tip: **H** A 'positive' test is one where the woman is pregnant. A 'negative' test means that the woman is not pregnant.

Control window

Pregnancy tests also have a control window. This shows the person using the test whether the test has worked correctly. The control window contains antibodies to the antibodies that are attached to the blue beads. This means that once the blue beads reach the control window, the antibodies attached to them will bind to the antibodies stuck to the control window. The control window should go blue both when a pregnancy test is positive and when it is negative. If it doesn't, it means the test has not worked.

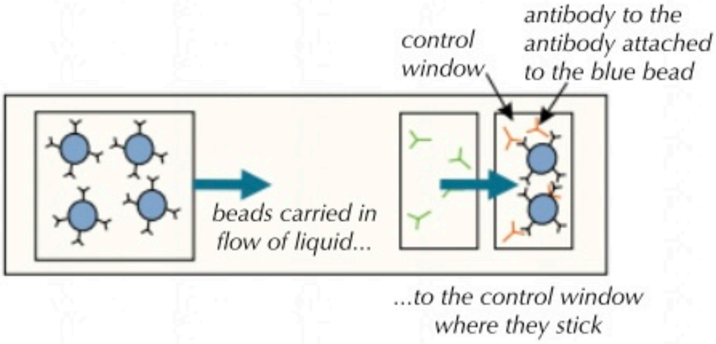

control window
antibody to the antibody attached to the blue bead
beads carried in flow of liquid...
...to the control window where they stick

Figure 5: *Diagram showing the control window in a negative test.*

Tip: **H** An antibody has a binding region which will only attach to one specific antigen or chemical. But a second antibody can use its own binding region to attach to a different part of the first antibody — it's an antibody to the antibody.

Tip: **H** A positive result should show two blue lines — one line on the test strip and one line on the control strip.

Diagnosing and treating cancer

Different cells in the body have different antigens on their cell surface. So you can make monoclonal antibodies that will bind to specific cells in the body (e.g. just liver cells). Cancer cells have antigens on their cell membranes that aren't found on normal body cells. They're called tumour markers. In the lab, you can make monoclonal antibodies that will bind to these tumour markers. These can be used to diagnose and treat cancer.

Diagnosis

First, the monoclonal antibodies are labelled with a radioactive element. The labelled antibodies are then given to a patient through a drip. They go into the blood and are carried around the body. When the antibodies come into contact with the cancer cells they bind to the tumour markers.

A picture of the patient's body is then taken using a special camera that detects radioactivity. Anywhere there are cancer cells will show up as a bright spot. Doctors can see exactly where the cancer is, what size it is, and find out if it is spreading.

Tip: **H** Monoclonal antibodies can also be used to treat diseases such as Crohn's disease.

Treatment

Monoclonal antibodies can also be attached to anti-cancer drugs. This might be a radioactive substance, a toxic drug or a chemical which stops cancer cells growing and dividing. The antibodies are given to the patient through a drip. The antibodies target specific cells (the cancer cells) because they only bind to the tumour markers. The drug kills the cancer cells but doesn't kill any normal body cells near the tumour.

Tip: **H** Radiotherapy involves firing high energy beams (like X-rays) straight at a tumour.

Other cancer treatments (like other drugs and radiotherapy) can affect normal body cells as well as killing cancer cells. So the side effects of an antibody-based drug are lower than for other drugs or radiotherapy.

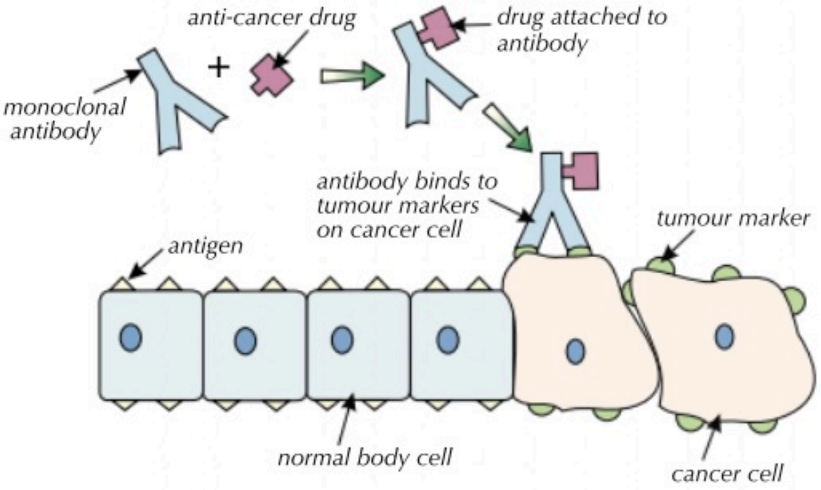


Figure 6: *Monoclonal antibodies being used in cancer treatment.*

Finding blood clots

When blood clots, proteins in the blood join together to form a solid mesh. Monoclonal antibodies have been developed that bind to these proteins.

You can attach a radioactive element to the monoclonal antibodies. Then, if you inject them into the body and take a picture using a camera that detects the radiation, that picture will have a really bright spot where there is a blood clot. This is useful because you can easily find a potentially harmful blood clot (and get rid of it before it harms the patient).

Practice Questions — Fact Recall

Q1 In a positive pregnancy test, what does the monoclonal antibody bind to?

Q2 Name a group of diseases that can be treated using monoclonal antibodies.

Practice Questions — Application

Q1 A woman has been diagnosed with a type of cancer.

a) A doctor wants to see how far the woman's cancer has spread. How could monoclonal antibodies be used to identify the location of cancer cells in the woman's body?

b) Part of the woman's treatment involves the use of monoclonal antibodies that are attached to a radioactive substance.

Identify and explain one advantage of using monoclonal antibodies as a form of cancer treatment over radiotherapy treatments.

Q2 A woman is taking a pregnancy test. She urinates on the part of the test stick that contains antibodies to a hormone that is present in urine during pregnancy. These antibodies are attached to blue beads.

A control window on the pregnancy test contains antibodies to the antibodies attached to the blue beads.

Suggest how the woman will know whether or not the pregnancy test has worked.

6. Developing Drugs

Drugs have to go through many stages, including discovery, development and testing before they can be made commercially available.

Learning Objective:

- Be able to describe that the process of developing new medicines, including antibiotics, has many stages, including discovery, development, preclinical and clinical testing.

Specification Reference 5.20

Drug discovery

The first stage in the development of a drug is discovery. This could happen in many different ways.

Example

Penicillin is an antibiotic (see p.178). It was discovered by Alexander Fleming when he was clearing out Petri dishes containing bacteria. He noticed that one of the dishes had mould on it, and the area around the mould was free of bacteria. The mould was producing penicillin, which was killing the bacteria.

Nowadays, most scientists use their knowledge of how a disease works to try and identify molecules that could be used as drugs to fight the disease. Once a new potential drug has been discovered, it needs to be developed. This involves preclinical and clinical testing.

Drug testing

Tip: Like all drugs, antibiotics (see p.178) undergo thorough drug testing.

Before newly discovered drugs can be given to the general public, they have to go through a thorough testing procedure to make sure they are safe and effective.

There are three main stages in drug testing — preclinical testing on human cells and tissues, preclinical testing on live animals, and clinical testing on human volunteers.

Preclinical testing

Figure 1: *A piece of tissue from a human intestine being used in drug testing.*

Cells and tissues

In preclinical testing, drugs are tested on human cells and tissues in the lab. However, you can't use human cells and tissues to test drugs that affect whole or multiple body systems, e.g. testing a drug for blood pressure must be done on a whole animal because it has an intact circulatory system.

Live animals

The next step in preclinical testing is to test the drug on live animals. This is to test efficacy (whether the drug works and produces the effect you're looking for), to find out about its toxicity (how harmful it is) and to find the best dosage (the concentration that should be given, and how often it should be given).

Clinical testing

If the drug passes the tests on animals then it's tested on human volunteers in a clinical trial.

First, the drug is tested on healthy volunteers. This is to make sure that it doesn't have any harmful side effects when the body is working normally. At the start of the trial, a very low dose of the drug is given and this is gradually increased.

If the results of the tests on healthy volunteers are good, the drugs can be tested on people suffering from the illness. The optimum dose is found — this is the dose of drug that is the most effective and has few side effects.

Placebos

To test how well the drug works, patients are randomly put into two groups. One is given the new drug, the other is given a **placebo** (a substance that looks like the drug being tested but doesn't do anything, e.g. a sugar pill). This is so the doctor can see the actual difference the drug makes — it allows for the placebo effect (when the patient expects the treatment to work and so feels better, even though the treatment isn't doing anything).

Example

A pharmaceutical company has developed a drug, Drug X, to help people with high blood cholesterol to lower their cholesterol level. The drug was tested on 1500 patients with high cholesterol. The patients were divided into two groups and over six months each patient had one tablet per day. One group had a tablet containing Drug X and the other group had a tablet without Drug X — the placebo.

Tip: People in the control group of a clinical trial should be similar to people in the treatment group, e.g. of a similar age, gender, etc. This helps to make sure the study is a fair test — see page 10 for more on making a study a fair test.

Blind and double-blind trials

Clinical trials are **blind** — the patient in the study doesn't know whether they're getting the drug or the placebo. In fact, they're often **double-blind** — neither the patient nor the doctor knows until all the results have been gathered (see Figure 2). This is so the doctors monitoring the patients and analysing the results aren't subconsciously influenced by their knowledge.

	Blind trial	Double-blind trial
Does the **patient** know whether they're getting the drug or the placebo?	no	no
Does the **doctor** know whether the patient is getting the drug or the placebo?	yes	no

***Figure 2:** Table summarising blind and double-blind trials.*

The results of drug testing and drug trials aren't published until they've been through peer review. This helps to prevent false claims.

Tip: Peer review is when other scientists check that the work is valid and has been carried out rigorously — see page 2.

When a drug has finally passed all of these tests, it still needs to be approved by a medical agency before it can be used to treat patients. All of this means that drugs are as effective and safe as possible.

The importance of drug testing

It's really important that drugs are tested thoroughly before being used to make sure they're safe. An example of what can happen when drugs are not thoroughly tested is the case of thalidomide...

Example

Thalidomide is a drug that was developed in the 1950s. It was intended as a sleeping pill, and was tested for that use. But later it was also found to be effective in relieving morning sickness in pregnant women.

Unfortunately, thalidomide hadn't been tested as a drug for morning sickness, and so it wasn't known that it could pass through the placenta and affect the fetus, causing abnormal limb development. In some cases, babies were born with no arms or legs at all. About 10 000 babies were affected by thalidomide, and only about half of them survived.

The drug was banned, and more rigorous testing procedures were introduced. More recently thalidomide has been used in the treatment of leprosy and other diseases, e.g. some cancers.

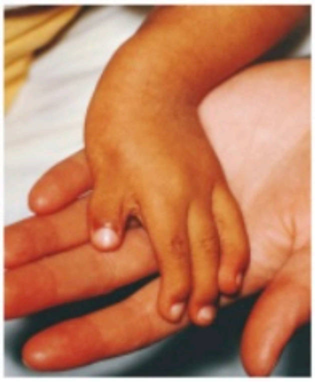


Figure 3: *This baby was born with a deformed hand due to thalidomide.*

Exam Tip
If you're asked what a placebo is in the exam, remember that it's not a drug — this is because it doesn't actually do anything.

Practice Questions — Fact Recall

Q1 What are drugs tested on in preclinical testing?

Q2 Give two things that drug testing aims to find out.

Q3 a) In a clinical trial, what type of volunteer is the drug tested on first — healthy volunteers or people suffering from the illness?

b) Describe the dosage of drug that is first used in a clinical trial.

Q4 What is a placebo?

Q5 Explain the difference between a blind and a double-blind trial.

Practice Questions — Application

Q1 For each of the drugs below, suggest what would have been given as a placebo when that drug went through clinical trials.

a) a paracetamol capsule

b) a steroid inhaler

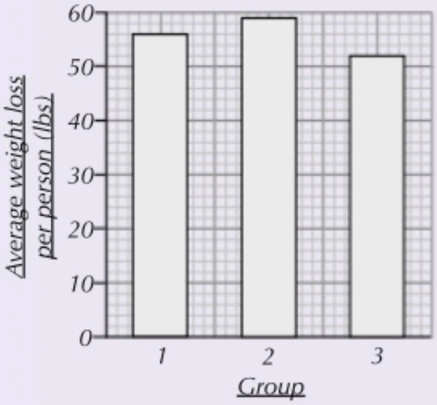
c) a cortisone injection

Q2 A new weight-loss pill has been developed called Drug Y.

The pill was tested in a double-blind clinical trial. It involved three groups of obese volunteers (50 per group), all of whom wanted to lose weight. Each group member took a pill three times a day for a year, alongside diet and exercise:

- Group 1 took Drug Y.
- Group 2 took a similar weight-loss pill already available (Drug Z).
- Group 3 took a placebo.

The average weight loss per person after one year is shown on the graph.



a) i) Would the doctors involved in this trial have known which patients were being given the placebo? Explain your answer.

ii) Suggest what could have been used as a placebo in this trial.

b) Suggest why Group 2 was included in the trial.

c) From these results, what can you conclude about Drug Y? Use data from the graph to support your answer.

Exam Tip
When answering a question about a clinical trial in the exam, make sure you read all the information you're given. Here you need to have spotted that it's a double-blind trial — this will help you answer Q2 a) i).

7. Antibiotics

Learning Objective:

- Be able to explain that antibiotics can only be used to treat bacterial infections because they inhibit cell processes in the bacterium but not in the host organism.

Specification Reference 5.16

Bacteria are singled-celled organisms that can divide rapidly in the right conditions. Most bacteria are harmless, like the ones in your gut that help digestion. But some can be pretty nasty. That's where antibiotics come in...

What are antibiotics?

Antibiotics are drugs that are used to treat bacterial infections. Antibiotics work by inhibiting processes in bacterial cells, but not in the host organism.

Example

Some antibiotics (e.g. penicillin) inhibit the building of bacterial cell walls — this prevents the bacteria from dividing, and eventually kills them, but has no effect on cells in the human host (which don't have cell walls).

Different antibiotics target different types of bacteria, so it's important to be treated with the right one.

Tip: Protein synthesis in bacteria is different to protein synthesis in host organisms so antibiotics won't affect protein synthesis in the host.

Example

Doxycycline is one of several antibiotics that can be given to patients suffering from an infection of chlamydia (caused by the bacterium *Chlamydia* — see p.156 for more). Doxycycline works by interrupting the synthesis of important proteins inside the bacteria that are needed for the bacteria to survive. As with all bacterial infections, many antibiotics are ineffective (e.g. daptomycin) or less effective (e.g. penicillin) at treating chlamydia, so doctor's need to make sure that they prescribe the correct antibiotic.

Antibiotics and viruses

Antibiotics don't destroy viruses (e.g. flu or cold viruses). This is because viruses are not cells (unlike bacteria) so they don't contain a cell wall or any of the machinery needed for growth and reproduction — this means antibiotics have no effect on them. Viruses can only reproduce inside a host organism's cells using the host cell's machinery. Since antibiotics don't affect the host cell either, the virus inside survives. It is very difficult to develop drugs that destroy just the virus without killing the body's cells.

Tip: A drug that targets a virus is known as an 'antiviral'.

Practice Questions — Fact Recall

Q1 What are antibiotics?

Q2 What can't all bacterial infections be treated with the same antibiotic?

Q3 Explain why antibiotics can't be used to kill viruses.

8. Investigating Antibiotics and Antiseptics

CORE PRACTICAL

You need to know how to grow bacteria in the lab. That includes how to grow them safely. Read on to find out how...

How are microorganisms cultured in the lab?

Bacteria (and some other microorganisms) are grown (cultured) in a "growth medium", which contains the carbohydrates, minerals, proteins and vitamins they need to grow. The growth medium used can be a nutrient broth solution or solid agar jelly. Bacteria grown on agar 'plates' will form visible colonies on the surface of the jelly, or will spread out to give an even covering of bacteria.

In the lab at school, cultures of microorganisms are not kept above 25 °C, because harmful pathogens (microorganisms that cause disease — see page 153) are more likely to grow above this temperature. In industrial conditions, cultures are incubated at higher temperatures to provide optimum conditions for growth.

Growing microorganisms on an agar plate

To make an agar plate, hot agar jelly is poured into shallow, round plastic dishes called Petri dishes. When the jelly's cooled and set, sterile inoculating loops (wire loops) can be used to transfer microorganisms to the agar jelly. Alternatively, a sterile dropping pipette and spreader can be used to get an even covering of bacteria. The microorganisms then multiply.

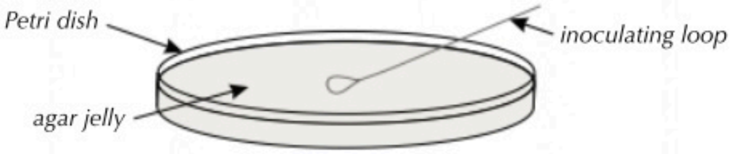


Figure 1: *An agar plate and inoculating loop.*

Investigating the effect of substances on bacterial growth

Antibiotics kill bacteria inside your body, whereas antiseptics kill bacteria outside of the body (e.g. on the skin). You can test the action of antibiotics and antiseptics on cultures of bacteria by carrying out the following steps (using antibiotics as an example):

1. Place paper discs soaked in different types (or different concentrations) of antibiotics on an agar plate that has an even covering of bacteria. Leave some space between the discs.
2. The antibiotic should diffuse (soak) into the agar jelly. Antibiotic-resistant bacteria (i.e. bacteria that aren't affected by the antibiotic — see p.125-126) will continue to grow on the agar around the paper discs, but non-resistant strains will die. A clear area will be left where the bacteria have died — this is called an inhibition zone (see Figures 3 and 4).

Learning Objectives:

- Be able to investigate the effects of antiseptics, antibiotics or plant extracts on microbial cultures. (Core Practical)
- Be able to explain the aseptic techniques used in culturing microorganisms in the laboratory, including use of an autoclave to prepare sterile growth medium and Petri dishes, the use of sterile inoculating loops to transfer microorganisms and the need to keep Petri dishes and culture vials covered.
- Be able to calculate cross-sectional areas of bacterial cultures and clear agar jelly using πr^2.

Specification References
5.17B – 5.19B

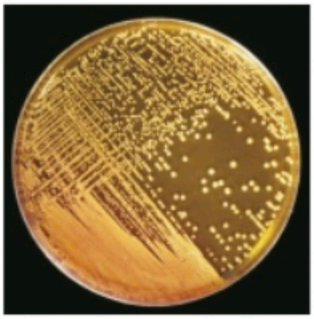


Figure 2: *Bacterial colonies on an agar plate.*

Tip: Working with microorganisms can be hazardous. Make sure you carry out a full risk assessment before you carry out this practical.

Tip: The control is not expected to have any effect on the bacteria.

3. Make sure you use a **control**. This is a paper disc that has not been soaked in an antibiotic. Instead, soak it in sterile water. You can then be sure that any difference between the growth of the bacteria around the control disc and around one of the antibiotic discs is due to the effect of the antibiotic alone (and not something weird in the paper, for example).

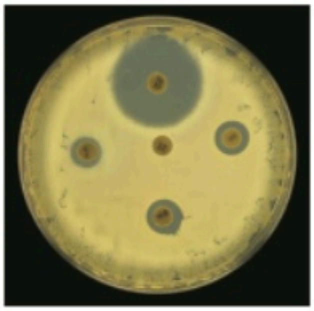


Figure 3: *Antibiotic discs on a bacterial culture. You can see clear zones around the discs where the bacteria can't grow.*

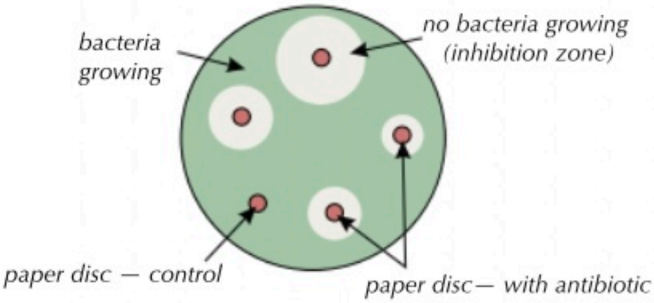

bacteria growing
no bacteria growing (inhibition zone)
paper disc — control
paper disc— with antibiotic

Figure 4: *An agar plate used to investigate the effect of antibiotics on bacteria.*

4. Leave the plate for 48 hours at 25 °C.
5. The more effective the antibiotic is against the bacteria, the larger the inhibition zone will be — see next page.

A similar method can be used to test the effects of antiseptics (or disinfectants) on bacterial growth — just replace the paper discs soaked in antibiotics with discs soaked in the solutions you're interested in. Alternatively, you could look at the effect of concentration of one antiseptic by soaking the discs in different concentrations of the same solution.

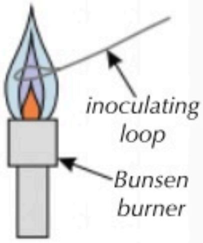
Tip: As many plants produce antiseptics in self-defence (see p.160), you can test the effects of different plant extracts in a similar way.

Preparing an uncontaminated culture

Contamination by unwanted microorganisms will affect your results and can potentially result in the growth of pathogens. To avoid this, the following **aseptic techniques** should be used:

Tip: If something is "aseptic", it is free from harmful microorganisms.

- The Petri dishes and growth medium must be sterilised before use. This can be done by placing them in a machine called an autoclave, which uses steam at a high pressure and temperature to kill any unwanted microorganisms that may be lurking on them.
- If an inoculating loop is used to transfer the bacteria to the culture medium, it should be sterilised first by passing it through a hot flame.



Tip: You need to let the inoculating loop cool down after sterilising it, otherwise you could kill the bacteria you pick up with it.

- Liquid bacterial cultures should be kept in a culture vial with a lid. The lid should only be removed briefly when transferring the bacteria, to prevent other microbes getting in.
- After transferring the bacteria, the lid of the Petri dish should be lightly taped on — to stop microorganisms from the air getting in.
- The Petri dish should be stored upside down — to stop drops of condensation falling onto the agar surface.

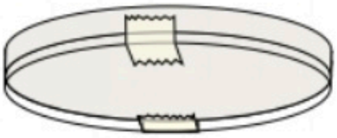


Figure 5: *The correct method of storing a Petri dish containing bacteria.*

Tip: Don't seal up the Petri dish completely before storing it — you need to let some oxygen get into the dish, otherwise you could end up growing some dangerous pathogens.

Measuring inhibition zones

You can compare the effectiveness of different antibiotics (or antiseptics or plant extracts) on bacteria by looking at the relative sizes of the inhibition zones. The larger the inhibition zone around a disc, the more effective the antibiotic is against the bacteria.

You can do this by eye if there are large differences in size. But to get more accurate results it's a good idea to calculate the area of the inhibition zones using their diameter (the distance across). You can measure this with a ruler — see Figure 6.

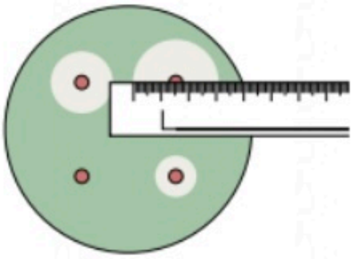


Figure 6: *Diagram showing a ruler being used to measure the diameter of an inhibition zone.*

Tip: Don't open the Petri dish to measure the inhibition zones — they should be visible through the bottom of the dish.

To calculate the area of an inhibition zone, you need to use this equation:

$$\text{Area} = \pi r^2$$

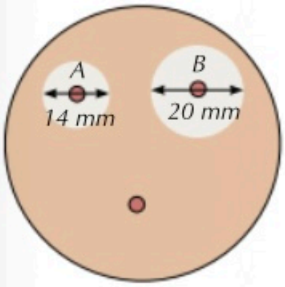
This is the equation for the area of a circle.
You're likely to use the units cm^2 or mm^2 for the area.

- r is the radius of the inhibition zone — it's equal to half the diameter.
- π is just a number. You should have a button for it on your calculator. If not, just use the value 3.14.

Tip: Measuring the diameter and then halving it to get the radius is more accurate than measuring the radius straight off, as it's hard to judge by eye exactly where the centre of the inhibition zone is.

Example

The diagram below shows the inhibition zones produced by antibiotics A and B. Use the areas of the inhibition zones to compare the effectiveness of the antibiotics.



1. Divide the diameter of zone A by two to find the radius:

   Radius of A $= 14 \div 2 = 7$ mm

2. Stick the radius value into the equation, area $= \pi r^2$:

   Area of A $= \pi \times 7^2 =$ **154 mm²**

3. Repeat steps 1 and 2 for zone B:

   Radius of B $= 20 \div 2 = 10$ mm

   Area of B $= \pi \times 10^2 =$ **314 mm²**

4. Compare the sizes of the areas.
   314 mm^2 is just over twice 154 mm^2, so you could say that:

The inhibition zone of antibiotic B is roughly twice the size of the inhibition zone of antibiotic A.

Tip: When you're comparing sizes, make sure that the values you're using are all in the same units.

Finding the area of a colony

The equation on the previous page can also be used to calculate the area of a bacterial colony. You just need to measure the diameter of the colony you are interested in first.

Tip: The size and shape of a bacterial colony on the surface of agar depends on the type of bacteria it's formed from.

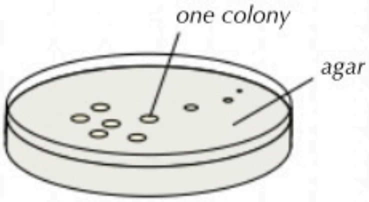
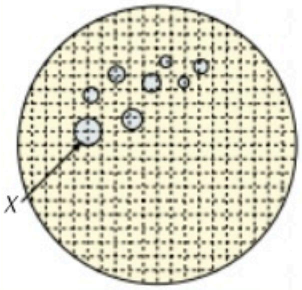


Figure 7: *Diagram showing bacterial colonies on an agar plate.*

Example

The diagram below shows bacterial colonies growing on an agar plate. A grid of 5 mm × 5 mm squares has been placed on the plate. Calculate the area covered by the colony labelled 'X'.



1. Work out the radius of X:

   The radius is the width of one square, which is 5 mm.

2. Stick the radius value into the equation, area = πr^2:

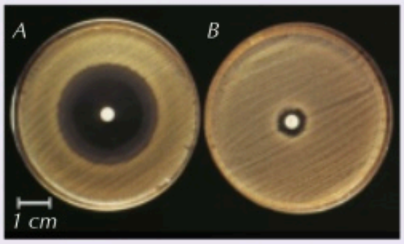
   Area of X = $\pi \times 5^2$ = **79 mm²**

Practice Questions — Application

Two different antibiotics were investigated for their effect on bacterial growth. The results of the investigation are shown below.

Q1 Copy and complete the table below by finding the diameter, radius and area of the inhibition zones for each of the antibiotics.

Give the value of the area to the nearest cm².



Antibiotic	Diameter (cm)	Radius (cm)	Area (cm²)
A			
B			

A control was used to show that the results of the investigation were due to the effect of the antibiotics on the bacteria.

Q2 What result would you expect to see if an antibiotic that was not effective against this strain of bacteria was used?

Q3 What can you conclude from the results of the investigation?

Tip: If an image has a scale bar, you can use the bar to work out the size of the real object. E.g. if there is a 5 mm scale bar that represents 2 cm (so it looks like this: 2 cm) and the image is 14 mm wide, the real object is (14 ÷ 5) × 2 = 5.6 cm wide.

Tip: When working out the area, remember to use 3.14 if you don't have a π button on your calculator.

Topic 5b Checklist — Make sure you know...

Defences Against Disease

☐ That the body has physical barriers to disease, which include the skin, mucus in the nose and airways, and cilia which line the trachea and bronchi.

☐ That the body has chemical barriers to disease, which include hydrochloric acid produced in the stomach and lysozymes.

☐ That if pathogens do manage to enter the body, the immune system can attack them — some white blood cells non-specifically engulf pathogens by phagocytosis, and other white blood cells called B-lymphocytes produce antibodies in response to antigens in the specific immune response.

☐ That antibodies bind to antigens on pathogens so that the pathogens can be found and destroyed by other white blood cells.

Memory Lymphocytes and Immunisation

☐ That when a foreign antigen on the surface of a pathogen enters the body for the first time, it triggers the production of specialised white blood cells called memory lymphocytes.

☐ That memory lymphocytes remain in the body for a long period of time and can 'remember' the antigen that triggered their production in the primary immune response to that antigen.

☐ That the secondary immune response is faster and stronger than the primary immune response, as memory lymphocytes recognise the antigens on the pathogen and mass produce antibodies specific to that antigen.

☐ That immunisation usually involves injecting dead or inactive pathogens to trigger the production of antibodies and memory lymphocytes. If a live version of the same pathogen then enters the body, memory lymphocytes can rapidly mass-produce the right antibodies to kill it so that the person is less likely to get ill.

Pros and Cons of Immunisation

☐ That immunisation programmes have helped to reduce and in some cases, eliminate, the occurrence of certain diseases in the UK, and that if enough people are immune to a certain pathogen, it can reduce the spread of the pathogen. This is known as herd immunity.

☐ That vaccinations don't always provide immunity, and that some people can have a bad reaction to a vaccine.

☐ That the risks of vaccination should be balanced up against the risk of catching the disease that the vaccine is designed to protect against.

Monoclonal Antibodies

☐ **H** That monoclonal antibodies are produced from lots of clones of a single B-lymphocyte, and that they will only bind to one specific protein antigen, so can target a particular cell or chemical.

☐ **H** How monoclonal antibodies are made — a lymphocyte (that doesn't divide easily) and myeloma cell (that divides lots) are fused to create a hybridoma, which is cloned to produce lots of identical cells which all produce the same antibodies.

cont...

Monoclonal Antibody Uses

- ☐ **H** That monoclonal antibodies are used in pregnancy tests, where they bind to a hormone (called HCG) present in the urine of pregnant women.
- ☐ **H** That monoclonal antibodies bound to a radioactive substance can be used to diagnose cancer — they bind to tumour markers on cancer cells in the body and are then detected by a special camera.
- ☐ **H** That monoclonal antibodies can treat cancer if they are attached to a radioactive substance, toxic drug or a chemical which stops cancer cells growing and dividing.
- ☐ **H** The advantages of using cancer treatments based on monoclonal antibodies, compared to other treatments for the disease.
- ☐ **H** That monoclonal antibodies attached to a radioactive element can be used to locate blood clots.

Developing Drugs

- ☐ That modern drug discovery involves scientists using knowledge of how a disease works to try and find molecules that could be used to treat the disease.
- ☐ That drugs have to be tested to make sure that they are safe and effective.
- ☐ That new drugs are first tested in preclinical trials on human cells and tissues as well as on live animals.
- ☐ That during preclinical drug trials on live animals, new drugs are tested for efficacy and toxicity, and also to find the best dose.
- ☐ That after preclinical testing, drugs are tested in clinical trials on healthy volunteers at low doses. They're then tested on ill volunteers to find the optimum dose of a drug.
- ☐ That a placebo is a substance that looks similar to the drug being tested but that doesn't do anything, and is used in clinical trials to find out if any improvement in the patients' conditions was from the drug, or if it was caused by the placebo effect.
- ☐ That in a blind trial, the volunteers don't know which volunteers have been given the drug and which volunteers have been given the placebo and in a double-blind trial, neither the doctors nor the volunteers know.

Antibiotics

- ☐ That antibiotics are used only to treat bacterial infections as they specifically target processes in bacterial cells, leaving the cells of the host organism unharmed.

Investigating Antibiotics and Antiseptics

- ☐ How to investigate the effect of antibiotics, antiseptics or plant extracts on microbial cultures (Core Practical).
- ☐ How the contamination of bacterial cultures is prevented by using aseptic techniques, such as using an autoclave to sterilise Petri dishes and culture medium, sterilising inoculating loops, taping lids onto Petri dishes and storing Petri dishes upside down, and keeping culture vials covered.
- ☐ How to calculate the area of an inhibition zone, or colony, using the equation: area = πr^2.

Exam-style Questions

1 Pathogens can enter the body in several ways.

(a) Outline how the stomach helps to defend the body against the entry of pathogens.

(1 mark)

(b) The human airways include the trachea and bronchi.
Outline how the trachea and bronchi help to defend the body against pathogens.

(3 marks)

(c) Describe how lysozyme acts as a chemical barrier to infection.

(1 mark)

Sometimes pathogens get past the body's defences.
This leads to the production antibodies by B-lymphocytes.

(d) Describe the role that antibodies play in the specific immune response.

(2 marks)

2 **Figure 1** shows the number of measles cases reported each year worldwide, along with the estimated immunisation coverage, from 1980 to 2014.

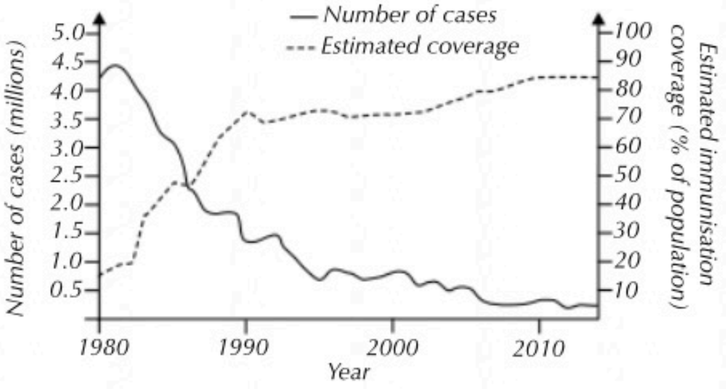


Figure 1

(a) Describe the trends shown in the graph.
Use data from the graph to support your answer.

(4 marks)

(b) Evaluate how far this data supports the case for immunising people against measles.

(3 marks)

(c) Describe how "herd immunity" could play a role in the prevention of an outbreak of measles.

(3 marks)

3* A woman takes a pregnancy test. The test displays two blue lines indicating that she is pregnant. Explain how pregnancy tests containing monoclonal antibodies work to show that a woman is pregnant.

(6 marks)

4 A new drug is being developed.

(a) Describe how modern scientists discover drugs with the potential to cure disease.

(1 mark)

(b) The new drug enters preclinical testing. Preclinical testing happens on cells and tissues, and it is sometimes done using live animals too.
Suggest why a drug designed to affect the absorption of nutrients from the small intestine into the bloodstream might be tested on live animals rather than just on cells and tissues.

(2 marks)

The drug then enters clinical trials.

(c)* Describe what happens at this stage.
Refer to placebos and double-blind testing in your answer.

(6 marks)

5 A doctor needs to find out which antibiotics will treat a patient's infection, so she sends a sample of bacteria taken from the patient to be cultured in the lab.

A lab technician fills a Petri dish with agar jelly containing nutrients. When this has set, he transfers the bacterial sample to the dish.

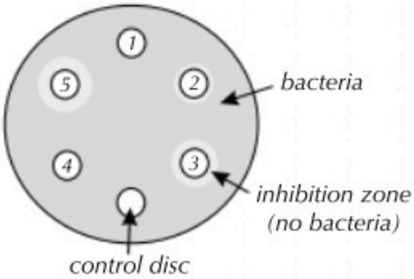
(a) Describe **two** steps the lab technician should take during this process to avoid contamination of the bacterial culture.

(2 marks)

Once the lab technician has transferred the bacteria, he places 5 different paper discs, each soaked in a different antibiotic, onto the agar. He also puts one paper disc that hasn't been soaked in antibiotic onto the agar. He leaves the Petri dish to incubate.

Figure 2 shows a diagram of the dish a few days later.

Figure 2



(b) From these results, which antibiotic (1-5) is the best one to use to treat the patient's infection? Explain your answer.

(3 marks)

(c) Give **two** variables that should have been controlled in order to make the results of this investigation valid.

(2 marks)

(d) What is the purpose of the control disc?

(1 mark)

1. Risk Factors for Non-Communicable Diseases

Non-communicable diseases can't be transmitted between individuals — see page 152. However, there are certain things that make developing a non-communicable disease more likely...

What are risk factors?

Risk factors are things that are linked to an increase in the likelihood that a person will develop a certain disease during their lifetime. They don't guarantee that someone will get the disease.

Risk factors can be unavoidable, e.g. a person's age or gender may make them more likely to get a disease. They can also be environmental (e.g. exposure to air pollution). But some risk factors are lifestyle factors that people can change, e.g. how much exercise they do or whether or not they smoke.

Many non-communicable diseases (including cardiovascular disease, cancer, liver and lung diseases, and obesity) are caused by several different risk factors interacting with each other rather than one factor alone. This means that the more risk factors you have for a disease, the more likely you are to get it.

Lifestyle-related risk factors for disease

You need to be able to explain the effect of the following lifestyle-related risk factors on disease.

Smoking

Smoking is a major risk factor associated with **cardiovascular disease** — that's any disease associated with the heart or blood vessels, e.g. a heart attack or stroke (see p.192). Heart attacks and strokes occur when the blood supply to the heart or brain is cut off. This stops oxygen reaching the heart or brain cells, causing them to die.

Smoking is a risk factor for these diseases for several reasons. One is that nicotine in cigarette smoke increases heart rate, which increases blood pressure. High blood pressure damages artery walls, which contributes to the build up of fatty deposits in the arteries. These deposits restrict blood flow and increase the risk of a heart attack or stroke. Smoking also increases the risk of blood clots forming in arteries, which can further restrict or block blood flow and lead to a heart attack or stroke.

Smoking is also a risk factor for **cancer** — in particular lung cancer. This is because cigarette smoke contains chemicals called carcinogens. These cause mutations in the genes that control cell division, which can lead to cancer (uncontrolled cell growth, see p.62).

Learning Objectives:

- Be able to describe that many non-communicable human diseases are caused by the interaction of a number of factors, including cardiovascular diseases, many forms of cancer, some lung and liver diseases and diseases influenced by nutrition.
- Be able to explain the effect of lifestyle factors on non-communicable diseases at local, national and global levels, including:
  - smoking on cardiovascular diseases;
  - alcohol on liver diseases;
  - exercise and diet on obesity and malnutrition.

Specification References 5.23, 5.24

Tip: The alleles you inherit may also make you more susceptible to developing a certain disease (see p.120).

Tip: Smoking is a risk factor for several lung diseases besides cancer, including emphysema and bronchitis.

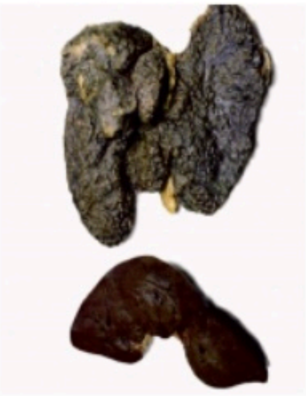


Figure 1: A liver with cirrhosis (top) and a normal liver (bottom).

Drinking alcohol

Drinking too much alcohol is a major risk factor for liver diseases, e.g. cirrhosis (scarring of the liver) and liver cancer.

Enzymes in the liver break down alcohol, but the breakdown products can damage liver cells. Liver cells may also be damaged when toxic chemicals leak from the gut due to damage to the intestines caused by alcohol. Drinking too much over a long period of time can cause permanent liver damage. It's also a risk factor for cardiovascular disease.

Diet

A diet with too few nutrients can lead to **malnutrition** (a condition where you don't have the right balance of nutrients to stay healthy). There are many different diseases associated with malnutrition.

Example

Scurvy is a disease caused by a deficiency (lack) of vitamin C in the diet. This affects the body's ability to produce collagen — an important protein found in tissues such as bone and tendons. Symptoms of scurvy include painful joints and muscles, as well as bleeding gums.

Exam Tip

In the exam, you might need to identify a correlation between risk factors and diseases from a graph. To recap what correlation is, look at page 18.

Malnutrition can also be caused by a diet with too many nutrients.

Example

A diet that's high in fat and sugar can lead to problems such as **obesity** (see page 190) and being overweight. Obesity itself is a risk factor for other non-communicable diseases, e.g. type 2 diabetes (see p.240) and cardiovascular disease.

Exam Tip

In the exam, you might need to read off data related to disease risk factors from a table, graph or chart, or explain what the data is showing. Remember to always check any units or graph scales carefully before answering any questions.

Low levels of exercise (physical activity)

Exercise is an important factor in maintaining a healthy weight. Those who don't get enough exercise are more likely to become overweight and obese, which can lead to further health problems. Inactive people are also more likely to develop high blood pressure and cardiovascular disease, as well as increasing their risk of certain cancers.

Local, national and global impacts

Lifestyle factors can have different impacts locally, nationally and globally.

Local impacts

Non-communicable diseases can have knock-on effects for local areas. For example, in areas where there are high levels of obesity, smoking or excess alcohol consumption, there's likely to be a high occurrence of certain non-communicable diseases, e.g. cardiovascular or liver disease. This can put pressure on the resources (money, beds, staff, etc.) of local hospitals.

National impacts

Non-communicable diseases are also costly at a national level because the National Health Service provides the resources for the treatment of patients all over the UK. And sometimes, people suffering from a non-communicable disease may not be able to work. A reduction in the number of people able to work can affect a country's economy.

Global impacts

As well as being costly, non-communicable diseases are very common, e.g. cardiovascular disease is the number one cause of death worldwide. In developing countries, malnutrition is also a big problem because people are not able to access enough food. The high cost and occurrence of these diseases can hold back the development of a country — so they have an effect at a global level.

Practice Questions — Fact Recall

Q1 What is meant by the term 'risk factor'?

Q2 Give two risk factors for disease that can be changed.

Q3 Give two diseases that smoking is a risk factor for.

Q4 Give a risk factor that is thought to cause type 2 diabetes.

Q5 Give an example of the effect of non-communicable diseases caused by lifestyle factors at a national level in the UK.

2. Measures of Obesity

Learning Objective:

- Be able to explain the effect of lifestyle factors on obesity and malnutrition, including BMI, using the BMI equation:

$$\text{BMI} = \frac{\text{mass (kg)}}{(\text{height (m)})^2}$$

and waist : hip calculations.

Specification Reference 5.24

You might remember from p.188 that obesity is a risk factor for several different non-communicable diseases. This means that it's important for doctors to be able to determine whether or not somebody is obese.

What is obesity and how is it measured?

Obesity means being very overweight and having too much body fat. However, you can't just say that anybody over a certain weight is obese. That's because people come in all sorts of shapes and sizes — your weight is affected by things like your height and your muscle mass, as well as the amount of fat your body stores. So doctors use measures such as the Body Mass Index (BMI) and waist-to-hip ratio to help them decide whether somebody is overweight or obese.

Body Mass Index (BMI)

The Body Mass Index (BMI) can be used a guide to help decide whether someone is underweight, a healthy weight, overweight or obese.
It's calculated from a person's height and mass, using this formula:

$$\text{BMI} = \frac{\text{mass (kg)}}{(\text{height (m)})^2}$$

Tip: $(\text{height (m)})^2$ means you multiply the height in metres by itself.

Once you have calculated a value for a person's BMI, you can refer to a table that shows how the different values are classified — see Figure 1. The thresholds used depend on the person's ethnicity.

BMI for people of white heritage	BMI for people in black, Asian or certain other minority ethnic groups	Weight Classification
less than 18.5	less than 18.5	underweight
18.5 - 24.9	18.5 - 22.9	healthy weight
25 - 29.9	23 - 27.4	overweight
30 or higher	27.5 or higher	obese

Figure 1: *Table showing weight classification by BMI.*

Tip: People in black, Asian or certain other minority ethnic groups are at a higher risk of obesity-related health problems at a lower BMI. This is why the BMI ranges for certain weight classifications differ between the first two columns of the table.

Example

Calculate the BMI of a person of white heritage who has a mass of 63.0 kg and is 1.70 m tall. Is this person overweight?

1. Put the numbers you've been given into the formula above. Give your answer to an appropriate number of significant figures (see p.15).

$$\text{BMI} = \frac{\text{mass (kg)}}{(\text{height (m)})^2} = \frac{63.0\text{ kg}}{1.70\text{ m}^2} = 21.799... = \mathbf{21.8\ kg\ m^{-2}\ (3\ s.f.)}$$

2. Look at the table in Figure 1. Find the category in which the BMI value you have calculated lies. Read across to find the weight classification.

   This person is not overweight — their BMI lies between 18.5 and 24.9 (the healthy weight range).

Exam Tip

Make sure you're using the correct units for height and mass in any BMI calculations. E.g. if you're given the height in cm, you'll need to convert it to m before you start your calculation. There's more on converting units on pages 19-20.

If you eat a high fat, high sugar diet and you don't do enough exercise, you're likely to take in more energy than you use. The excess energy is stored as fat, so you're more likely to have a high BMI and be obese.

BMI isn't always a reliable measure of obesity. For example, athletes have lots of muscle, which has a higher mass than fat, so they can come out with a high BMI even though they're not overweight.

Tip: As you can see from Figure 1, BMI can be used to tell if someone is underweight (and therefore that they might not be getting enough nutrients) as well as if they are overweight.

Waist-to-hip ratio

A waist-to-hip ratio helps to measure fat distribution. To calculate it, you need to measure a person's hip circumference at its widest part, as well as the circumference of their waist. You can then use the following formula to figure out their waist-to-hip ratio:

Tip: The circumference of a person's waist or hips is the distance the whole way around their body at that point.

$$\text{waist-to-hip ratio} = \frac{\text{waist circumference}}{\text{hip circumference}}$$

Example

MATHS SKILLS

Calculate the waist-to-hip ratio of a person who has a waist circumference of 69 cm and a hip circumference of 98 cm.

$$\text{waist-to-hip ratio} = \frac{\text{waist circumference}}{\text{hip circumference}} = \frac{69\text{ cm}}{98\text{ cm}} = 0.7040... = \mathbf{0.70}\ (2\text{ s.f.})$$

Exam Tip
When calculating the waist-to-hip ratio, make sure that the waist circumference and the hip circumference are in the same units.

The higher your waist-to-hip ratio, the more weight you're likely to be carrying around your middle. A ratio above 1.0 for males and above 0.85 for females indicates that too much weight is being carried around the middle — this is known as abdominal obesity. A person with abdominal obesity has a greater risk of developing obesity-related health problems, such as cardiovascular disease (see next page) and type 2 diabetes (see p.240), than someone who carries more weight around their hips.

It can be helpful to look at both a person's BMI and waist-to-hip ratio to measure their health. It's possible that a person could have a normal BMI but carry more weight around their stomach than their hips, therefore putting them at greater risk of certain non-communicable diseases.

***Figure 2:** A woman measuring the circumference of her waist.*

Practice Question — Application

Q1 Robyn is of white heritage, weighs 77.0 kg and is 178 cm tall. Asuka is of Asian heritage, 75.0 kg and is 155 cm tall.

a) Calculate the BMI of each of the women.

b) Use Figure 1 on the previous page to find the weight classification of each of the women. Which woman may be recommended to lose weight by a doctor?

3. Treating Cardiovascular Disease

Cardiovascular disease is one of the main causes of death in the UK. We have many ways to effectively treat it. Read on for more...

Learning Objective:

- Be able to evaluate some of the treatments for cardiovascular disease, including lifestyle changes, life-long medication and surgical procedures.

Specification Reference 5.25

Tip: See pages 264-268 for more on blood vessels and the heart.

What is cardiovascular disease?

Cardiovascular disease (CVD) is a term used to describe diseases of the heart or blood vessels. It is generally associated with the narrowing and blockage of **arteries** (blood vessels that carry blood away from the heart).

Arteries narrow when fatty deposits build up inside them (see Figure 1). The deposits occur in areas where the artery wall has been damaged, e.g. by high blood pressure. The deposits can also trigger blood clots to form, which can block blood flow completely.

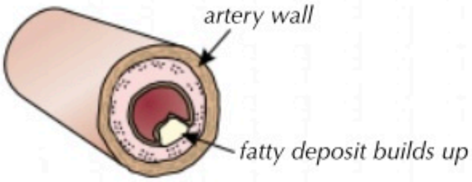


Figure 1: *Fatty deposits building up in an artery.*

Tip: Lifestyle-related risk factors for CVD include smoking, drinking too much alcohol, obesity, a diet high in saturated fats and a lack of exercise. There's more on risk factors on p.187-189.

Several different diseases can be classed as cardiovascular diseases.

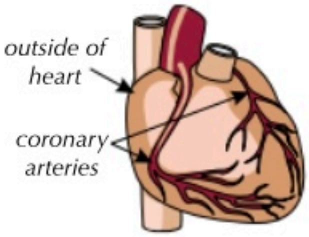


Figure 2: *The location of the coronary arteries.*

Examples

- Coronary heart disease is when fatty deposits build up in the arteries that supply blood to the heart muscle (the coronary arteries). This causes the arteries to become narrow, so blood flow to the heart is restricted. If blood clots also form and completely block the blood flow in the coronary arteries, the heart muscle will be deprived of oxygen. This causes a heart attack.
- A stroke occurs when an already narrowed artery supplying the brain with blood is blocked by a blood clot. This cuts off the blood supply to the brain and deprives the brain of oxygen.

Depending on the extent of the severity of the disease, CVD can be treated in a few different ways.

Tip: There are other factors which can also increase the risk of developing CVD, such as age, gender and family history. While these risk factors can't be changed, it is possible to control and modify lifestyle-related risk factors.

Lifestyle changes

Making changes to your lifestyle can reduce your risk of developing CVD. If you already have CVD, these changes can form part of the treatment, helping to reduce the risk of a further heart attack or stroke. Lifestyle changes are often recommended first because they don't really have any downsides.

People with (or at risk of) CVD may be encouraged to eat a healthy, balanced diet, which is low in saturated fat (as saturated fat can increase the level of 'bad' cholesterol in the blood — see next page). They may also be encouraged to exercise regularly, lose weight if necessary and stop smoking.

Life-long medication

Lifestyle changes aren't always enough to treat CVD. Sometimes medicines are needed too. Some people may need to take these medicines for the rest of their lives.

Statins

Statins are drugs that can reduce the amount of 'bad' cholesterol (also known as LDL cholesterol) present in the bloodstream. Having too much 'bad' cholesterol in the bloodstream can cause fatty deposits to form inside arteries, which can lead to coronary heart disease. Taking statins slows down the rate of fatty deposits forming, which can reduce the risk of strokes and heart attacks.

Unfortunately, statins also have their disadvantages. Statins are a long-term drug that must be taken regularly. There's the risk that someone could forget to take them. Also, statins can sometimes cause negative side effects, e.g. headaches and aching muscles. Some of these side effects can be serious, e.g. kidney failure, liver damage and memory loss. Another disadvantage is that the effect of statins isn't instant. It takes time for their effect to kick in.

Tip: Cholesterol is an essential lipid that your body produces and needs to function properly. However, high levels of 'bad' (LDL) cholesterol in your bloodstream can cause health problems.

Antihypertensives

Antihypertensives reduce blood pressure. This helps to prevent damage to blood vessels and so reduces the risk of fatty deposits forming. This reduces the risk of cardiovascular disease. There are different types of antihypertensive medications, which reduce blood pressure in different ways.

Examples

- Diuretics — help flush out excess water.
- ACE inhibitors — relax blood vessels.
- Beta blockers — cause the heart to beat slower and less forcefully.

Each type of medication has it's own set of side effects, such as headaches and dizziness.

Exam Tip
In the exam, you could be asked to evaluate different treatments for CVD — if so, make sure you write about both the advantages and disadvantages of the treatments you're asked about.

Anticoagulants

Blood clots are more likely to form in patients with cardiovascular disease. This, coupled with the narrowing of arteries in CVD, increases the likelihood of blood clots blocking blood flow to vital organs. Anticoagulants (e.g. Warfarin™) are drugs which make blood clots less likely to form. This reduces the risk of blood clots causing problems such as heart attacks and strokes.

However, blood clotting is needed to prevent excessive bleeding. Patients taking anticoagulants are more likely to suffer from heavy bleeding if they're injured. This can result in significant blood loss if the injury is severe. Anticoagulants can also sometimes increase the risk of internal bleeding.

Exam Tip
When prescribing medicine, doctors have to weigh up the possible side effects against the risk of disease.

Surgical procedures

Sometimes the damage caused by cardiovascular disease needs to be treated with surgery. Any heart surgery is a major procedure and so there is always risk of bleeding, clots and infection. The longer and more complex the surgery, the greater the risk of such complications.

Exam Tip Make sure that you're clear about what you're being asked to do when answering data questions. If you're asked to describe what some data shows, you'll just need to give any patterns or trends. If the question wants you to explain the data, you'll need to apply your scientific knowledge to give reasons for the trends.

Stents

Stents are wire mesh tubes that can be inserted inside arteries to widen them and keep them open. They are particularly useful in people with coronary heart disease.

Stents keep the coronary arteries open, making sure blood can pass through to the heart muscles (see Figure 3). This keeps the person's heart beating (and the person alive).

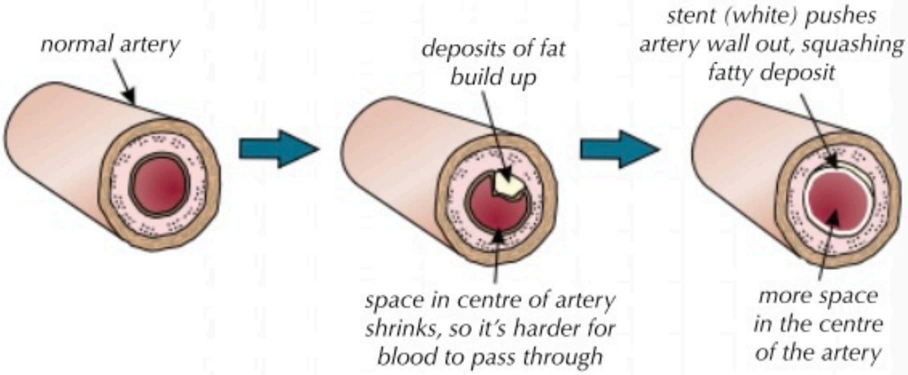

normal artery
deposits of fat build up
stent (white) pushes artery wall out, squashing fatty deposit
space in centre of artery shrinks, so it's harder for blood to pass through
more space in the centre of the artery

Figure 3: *A diagram showing how a stent can help to widen an artery.*

Figure 4: *A stent that can be used to widen an artery.*

Stents are a way of lowering the risk of a heart attack in people with coronary heart disease. They are effective for a long time and the recovery time from the surgery is relatively quick.

However, there is a risk of complications during the operation (e.g. a heart attack) and a risk of infection from surgery. Over time, the artery can narrow again as the stents can irritate the artery and make scar tissue grow. There's also the risk of a patient developing a blood clot near the stent — the patient needs to take anticoagulants to reduce this risk.

Tip: Sampling is often used when collecting data related to health and disease. This is because it would take too long and cost too much to collect data from the entire population. Large samples are better than small samples. See p.321-322 for more on sampling.

Coronary bypass surgery

It's not always appropriate to insert a stent (for example, in cases when a patient has several blocked blood vessels). In such cases, blood flow to the heart can be improved by carrying out coronary bypass surgery. This is where a piece of healthy vessel is taken from elsewhere in the body and used to bypass a blocked section of the coronary arteries.

Coronary bypass surgery is longer and more invasive than surgery to insert a stent and so carries greater risk of complications. It also requires a longer stay in hospital following the operation and has a longer recovery time. However, there's a lower chance that the surgery will need to be repeated. (Repeat surgery can be necessary with stents if the artery narrows again.)

Donor hearts

Heart transplants are necessary in cases where heart disease is severe. The whole heart can be replaced with a donor heart. Although heart transplants can be life saving operations, they do have disadvantages.

Examples

- The new heart does not always start pumping properly, so further treatment is needed to help blood circulation until it improves.
- Sometimes the immune system recognises the donor heart as foreign and attacks it. This is called rejection. To reduce the risk of rejection, patients must take immunosuppressant drugs for the rest of their life. These drugs suppress the immune system, but by doing so, make the patient more vulnerable to infection.

Tip: Patients must be compatible with the donor heart so that their body doesn't reject it. This means that there can be a long waiting list for donor hearts.

Practice Questions — Fact Recall

Q1 What is cardiovascular disease?

Q2 How do drugs that help to reduce blood pressure (antihypertensives) treat cardiovascular disease?

Q3 Give one risk of having any kind of surgery to treat cardiovascular disease.

Practice Question — Application

Q1 Clifford is diagnosed with cardiovascular disease.
The doctor advises Clifford to stop smoking. Explain why.

Q2 A patient has been told he has cardiovascular disease. The doctors tell the patient he needs a surgical procedure to treat his condition. He is given information about having a stent inserted and about coronary bypass surgery. Some of the information is shown in the table below.

	Stent	Coronary bypass surgery
Time surgery takes	30 minutes - 2 hours	3-6 hours
Length of hospital stay	0-1 days	7 days or more
Approximate recovery time	1 week	6-12 weeks
Other information	Repeat surgery may be needed if artery narrows again	Less likely to need repeat surgery

After discussing his options with his doctor, the patient chooses to have a stent inserted rather than have coronary bypass surgery. Using information from the table, evaluate why the patient may have made this choice.

Topic 5c Checklist — Make sure you know...

Risk Factors for Non-Communicable Diseases

- ☐ That risk factors are things linked to an increased likelihood that a person will develop a disease.
- ☐ That many non-communicable diseases, including cardiovascular disease, cancer, liver and lung diseases and obesity are caused by several different risk factors interacting with each other.
- ☐ Why smoking is a risk factor for cardiovascular disease and alcohol is a risk factor for liver disease.
- ☐ Why a diet with too few or too many nutrients is a risk factor for malnutrition, and that a diet high in fat and sugar and a lack of exercise are risk factors for obesity.
- ☐ How non-communicable diseases have effects at local, national and global levels.

Measures of Obesity

- ☐ That Body Mass Index (BMI) and waist-to-hip ratio can be used as measures of obesity.
- ☐ That BMI can be used as a guide to determine whether a person is underweight, normal weight, overweight or obese.
- ☐ That BMI is calculated using the formula: BMI = mass (kg) ÷ (height (m))^2.
- ☐ Why diets high in fat and sugar, coupled with physical inactivity, can increase the likelihood of a high BMI and obesity.
- ☐ That the waist-to-hip ratio is a measure of fat distribution, which is calculated using the formula: waist-to-hip ratio = waist circumference ÷ hip circumference.
- ☐ That a high waist-to-hip ratio indicates that a person is carrying too much weight around their middle, increasing the risk of obesity-related problems.

Treating Cardiovascular Disease

- ☐ That cardiovascular disease can be treated by making lifestyle changes to reduce risk and that such changes are recommended for treatment first as they don't really have any downsides.
- ☐ That cardiovascular disease can be treated using life-long medications, such as statins to reduce 'bad' cholesterol in the blood, antihypertensives to reduce blood pressure and anticoagulants to reduce blood clotting, and that these medications have both advantages and disadvantages.
- ☐ That surgical procedures can be used to treat cardiovascular disease, including stents, coronary bypass surgery and heart transplants, and that all types of heart surgery carry major risks.
- ☐ How to evaluate relevant information and data describing treatments for cardiovascular disease.

Exam-style Questions

1 Moira has a hip circumference of 89 cm and a waist circumference of 0.72 m.

(a) Calculate Moira's waist-to-hip ratio. Give your answer to 2 significant figures.

(2 marks)

(b) Nadira has a waist-to-hip ratio of 0.92. Using your answer to part a), suggest whether Moira or Nadira is at more risk of developing type 2 diabetes. Explain your answer.

(2 marks)

(c) It is recommended that adults should not regularly drink more than 14 units of alcohol a week. Moira drinks 22 units of alcohol a week. Suggest **one** non-communicable disease that Moira is at risk of developing. Explain why.

(2 marks)

2 After a heart attack, many patients have a stent fitted into the affected coronary artery. A stent is a tube inserted into an artery to keep it open. It could be a bare-metal stent or a drug-eluting stent, which gradually releases a drug to prevent new cells from growing over the stent.

In a trial, patients needing a stent were randomly given either a bare-metal stent or a drug-eluting stent. Following their surgery, the patients were monitored and any problems recorded.

154 patients received the drug-eluting stent and 153 patients received the bare-metal stent. **Figure 1** shows how many patients experienced certain problems following stent surgery:

Figure 1

	Number of patients who died following treatment	Number of patients who had another heart attack	% of patients whose artery renarrowed
Drug-eluting stent	3	3	9
Bare-metal stent	7	3	21

(a) Calculate the percentage of patients that died after receiving the drug-eluting stent.

(1 mark)

(b) Suggest why stents are often used in people who have had a heart attack.

(2 marks)

(c) Based on the information given, some doctors may conclude that drug-eluting stents are more beneficial than bare-metal stents. Do you think this is a valid conclusion? Explain your answer.

(3 marks)

Topic 6 Plant Structures and Their Functions

1. Photosynthesis

Plants make their own food using energy from the Sun, a substance called chlorophyll, carbon dioxide from the air and water from the soil.

Learning Objectives:

- Be able to describe photosynthesis in plants and algae as an endothermic reaction that uses light energy to react carbon dioxide and water to produce glucose and oxygen.
- Be able to describe photosynthetic organisms as the main producers of food and therefore biomass.

Specification References
6.1, 6.2

What is photosynthesis?

Photosynthesis is the process that produces 'food' in organisms such as green plants and algae. The 'food' it produces is **glucose** (a sugar). Photosynthesis uses energy from the Sun to convert carbon dioxide and water into glucose and oxygen.

Some of the glucose is used to make larger, complex molecules that the organisms need to grow. These make up the organisms' **biomass** — the mass of living material in the organisms. The energy stored in the plants' and algae's biomass works its way through the food chain as animals eat them and each other. So photosynthetic organisms are the main producers of food for nearly all life on Earth.

Tip: Plants can use glucose to make a variety of things, such as cell walls and proteins.

Where does photosynthesis happen?

Photosynthesis takes place in **chloroplasts** in green plant cells — they contain pigments like **chlorophyll** that absorb light. Energy is transferred to the chloroplasts by light. Photosynthesis is **endothermic** — this means energy is transferred from the environment in the process.

Tip: Exothermic reactions transfer energy to the surroundings and endothermic reactions transfer energy from the surroundings.

Photosynthesis happens in the leaves of all green plants — this is largely what the leaves are for. Figure 2 shows a cross-section of a leaf showing the four raw materials (carbon dioxide, water, light and chlorophyll) needed for photosynthesis.

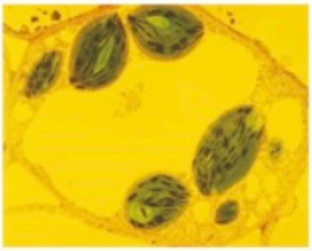


***Figure 1:** Microscope image of a plant cell. The green structures are chloroplasts.*

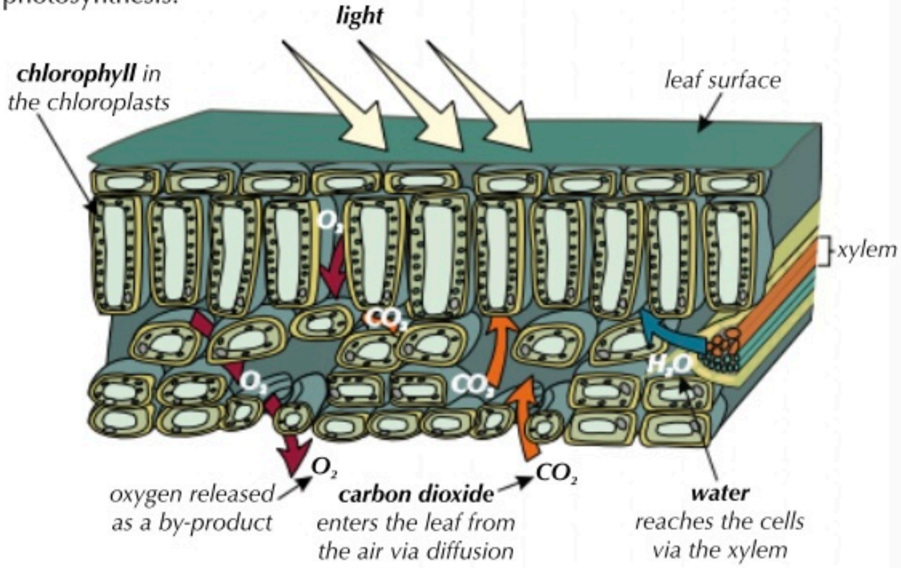

light
***chlorophyll** in the chloroplasts*
leaf surface
xylem
O_2
CO_2
H_2O
O_2
oxygen released as a by-product
CO_2
***carbon dioxide** enters the leaf from the air via diffusion*
***water** reaches the cells via the xylem*

***Figure 2:** Diagram of a cross-section through a leaf, showing the four raw materials required for photosynthesis.*

Tip: Xylem is the tissue that transports water around a plant (see page 207).

Word equation

The word equation for photosynthesis is:

$$\text{carbon dioxide} + \text{water} \xrightarrow{\text{light}} \text{glucose} + \text{oxygen}$$

Symbol equation

There's a symbol equation for photosynthesis too:

$$6CO_2 + 6H_2O \xrightarrow{\text{light}} C_6H_{12}O_6 + 6O_2$$

Exam Tip
You should learn these photosynthesis equations — they could get you easy marks in the exam.

Practice Questions — Fact Recall

Q1 Which product produced by photosynthesis is 'food' for the plant?

Q2 Which gas is used in photosynthesis?

Q3 Which gas is produced by photosynthesis?

Q4 a) Name the parts of a plant cell that contain chlorophyll.

b) What role does chlorophyll play in photosynthesis?

Q5 Photosynthesis is a reaction that takes in energy from the surroundings. Give the name for this type of reaction.

Q6 Write out the word equation for photosynthesis.

Q7 Name the chemical substance with the symbol $C_6H_{12}O_6$.

Practice Question — Application

Q1 Three identical plants were grown for a week. They were treated in exactly the same way, except they each received different amounts of sunlight per day, as shown in this table:

Plant	Hours of sunlight received per day
A	3
B	7
C	10

The plants didn't have any source of light other than sunlight.

Which plant do you think will have produced the most glucose after one week? Explain your answer.

2. Limiting Factors in Photosynthesis

Learning Objectives:

- Be able to explain the effect of light intensity, carbon dioxide concentration and temperature as limiting factors on the rate of photosynthesis.
- H Be able to explain the interactions of light intensity, carbon dioxide concentration and temperature in limiting the rate of photosynthesis.

Specification References 6.3, 6.4

Photosynthesis doesn't always happen at the same rate — factors such as light intensity, carbon dioxide level and temperature can all affect the rate.

What is a limiting factor?

The rate of photosynthesis is affected by the intensity of light, the concentration of carbon dioxide (CO_2), and the temperature. All three of these things need to be at the right level to allow a plant to photosynthesise as quickly as possible. If any one of these factors is too high or too low, it will become the **limiting factor**. This just means it's the factor which is stopping photosynthesis from happening any faster.

Which factor is limiting at any particular time depends on the environmental conditions:

Examples

- At night there's much less light than there is during the day, so light intensity is usually the limiting factor at night.
- In winter it's usually cold, so a low temperature is often the limiting factor.
- If it's warm enough and bright enough, the amount of CO_2 is usually limiting.

Tip: Plants also need water for photosynthesis, but when a plant is so short of water that it becomes the limiting factor in photosynthesis, it's already in such trouble that this is the least of its worries.

Limiting factors in photosynthesis

You need to be able to explain how light intensity, carbon dioxide concentration and temperature affect the rate of photosynthesis.

1. Effect of light intensity

Light provides the energy needed for photosynthesis. As the light intensity (strength of light) increases, photosynthesis gets faster.

H After a certain point, if you increase the light intensity, it won't make any difference — as light intensity increases, the rate will no longer increase. This is because it will be either the temperature or the carbon dioxide level which is now the limiting factor, not light. This is shown in Figure 1.

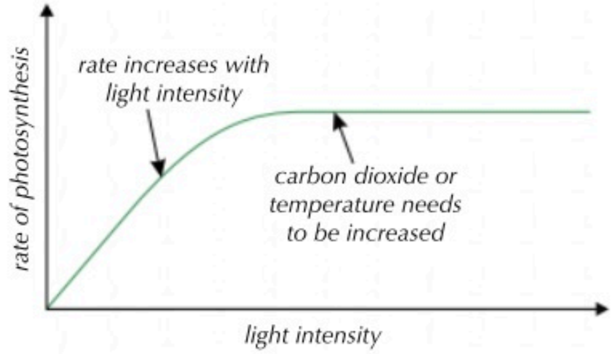


***Figure 1:** Graph showing how light intensity affects the rate of photosynthesis.*

Tip: H In Figure 1, photosynthesis hasn't stopped happening when the graph levels off — it's just that the rate of photosynthesis is not increasing anymore.

H In the lab you can change the light intensity by moving a lamp closer to or further away from your plant (see page 204 for this experiment). But if you just plot the rate of photosynthesis against "distance of lamp from the plant", you get a weird-shaped graph. To get a graph like the one in Figure 1, you either need to measure the light intensity at the plant using a light meter or calculate the relative light intensity using a nifty bit of maths called the inverse square law — see page 206.

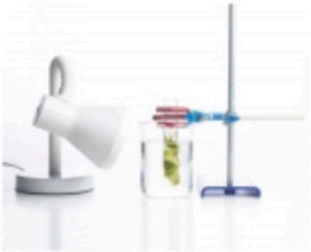


***Figure 2:** The number of bubbles produced in a set time can be counted to estimate the rate of photosynthesis, but a more accurate set-up can be seen on pages 204-205.*

2. Effect of carbon dioxide concentration

CO_2 is one of the raw materials needed for photosynthesis, so the rate of photosynthesis increases as the carbon dioxide concentration increases.

H As with light intensity, the amount of CO_2 will only increase the rate of photosynthesis up to a point. After this the graph flattens out — as the amount of CO_2 increases, the rate no longer increases (see Figure 3). This shows that CO_2 is no longer the limiting factor — at this point, either temperature or light intensity will be limiting the rate of photosynthesis.

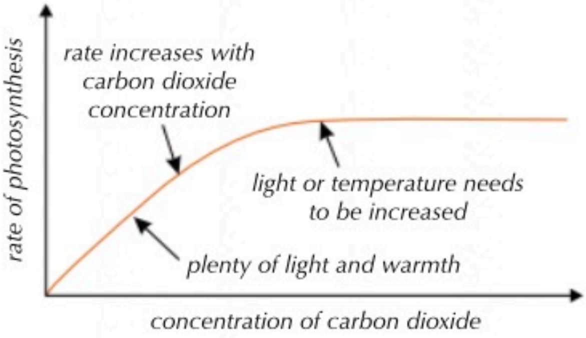


***Figure 3:** Graph showing how carbon dioxide concentration affects the rate of photosynthesis.*

Tip: If you're investigating the rate of photosynthesis using a plant in water, you can increase the CO_2 level by dissolving sodium hydrogencarbonate in the water. This gives off carbon dioxide.

3. Effect of temperature

Photosynthesis gets faster as the temperature increases, but only up to a certain temperature. If it gets too hot, the rate of photosynthesis slows down and it can even stop altogether.

Enzymes are proteins which increase the speed of chemical reactions in living things — so enzymes increase the rate of photosynthesis in plant cells. The speed at which enzymes work is affected by temperature.

Tip: You can read more about enzymes on pages 36-38.

Usually, if the temperature is the limiting factor in photosynthesis it's because it's too low — the enzymes needed for photosynthesis work more slowly at low temperatures. But if the plant gets too hot, the enzymes it needs for photosynthesis and its other reactions will be damaged. This happens at about 45 °C (which is pretty hot for outdoors, although greenhouses can get that hot if you're not careful).

Figure 4, on the next page, shows the effect that temperature has on the rate of photosynthesis.

Tip: The highest point (the peak) of the graph in Figure 4 is the optimum temperature of the reaction. See page 37 for more.

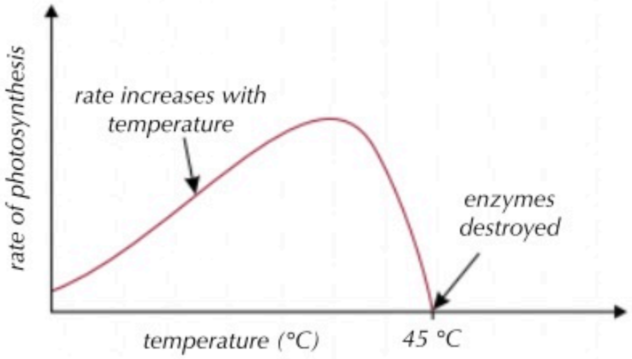


Figure 4: *Graph showing how temperature affects the rate of photosynthesis.*

4. Graphs showing more than one limiting factor Higher

You can show the effect of more than one limiting factor on the same graph:

Example **Higher**

Figure 5 shows how the rate of photosynthesis is affected by changing light intensity for two reactions carried out at different temperatures.

At the start of the graph, the rate of photosynthesis increases steadily as the light intensity increases for both reactions. At this point, light intensity is the limiting factor for both.

The lines level off when light intensity is no longer the limiting factor. The 15 °C line levels off at a lower point than the 25 °C line — at this point temperature must have become the limiting factor for the reaction at 15 °C.

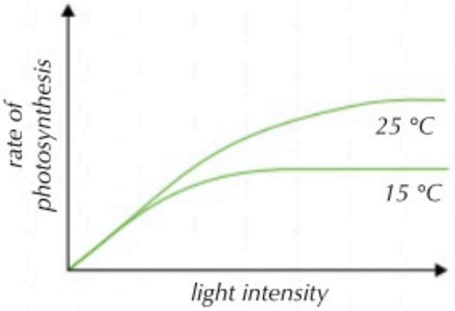


Figure 5: *Graph showing how rate of photosynthesis is affected by both light intensity and temperature.*

Practice Question — Fact Recall

Q1 The rate of photosynthesis is affected by limiting factors.

a) What is meant by a 'limiting factor' of photosynthesis?

b) Apart from light intensity, name two other factors that affect the rate of photosynthesis.

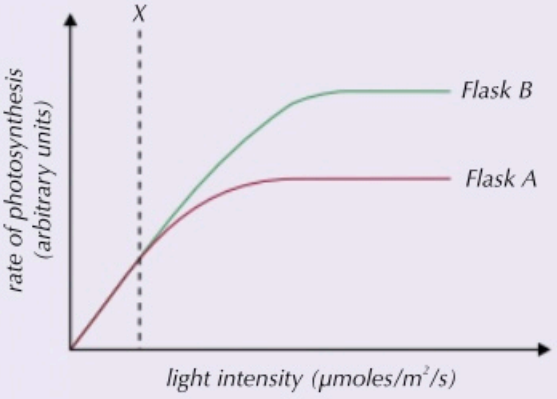
c) Describe the effect of increasing light intensity on the rate of photosynthesis.

Practice Questions — Application

Q1 Complete the table to show what is most likely to be the limiting factor of photosynthesis in the environmental conditions listed.

Environmental conditions	Most likely limiting factor
Outside on a cold winter's day.	
In an unlit garden at 1:30 am, in the UK, in summer.	
On a windowsill on a warm, bright day.	

Q2 Peter was investigating the rate of photosynthesis in pondweed. He put equally sized samples of pondweed in two separate flasks, A and B. Flask A had a lower carbon dioxide concentration than flask B. Peter put the flasks an equal distance away from a light source. He gradually increased the intensity of the light during the experiment. He kept both flasks at a constant temperature of 25 °C. Peter's results are shown on the graph below:



a) Peter thinks that the limiting factor before point X in his experiment is light. Explain why he is right.

b) Suggest why the line for Flask A levels off at a lower point than the line for Flask B. Explain your answer.

Exam Tip H

μmoles/m²/s is a unit used to measure light intensity. Don't panic if you see unfamiliar units in the exam — just focus on what the axis is showing you, e.g. here it's light intensity.

3. Investigating the Rate of Photosynthesis

CORE PRACTICAL

Learning Objective:

- Be able to carry out an experiment to investigate the effect of light intensity on the rate of photosynthesis (Core Practical).

Specification Reference 6.5

You need to know how to collect data about how light intensity affects the rate of photosynthesis. Handily, that's what these pages are all about.

Investigating the rate of photosynthesis

To investigate the effect of different light intensities on the rate of photosynthesis, you need to be able to measure the rate. One way to do this involves an aquatic plant, such as Canadian pondweed. The rate at which the pondweed produces oxygen corresponds to the rate at which it's photosynthesising — the faster the rate of oxygen production, the faster the rate of photosynthesis. Here's how the experiment works:

- A source of white light is placed at a specific distance from a conical flask containing the pondweed. Leave the pondweed for a couple of minutes to adjust to the new light intensity before starting the experiment.
- When you're ready to start, connect a gas syringe to the conical flask and leave the pondweed to photosynthesise for a set amount of time.
- As it photosynthesises, the oxygen released will collect in the gas syringe. This allows you to accurately measure the volume of oxygen produced.

Tip: Make sure you do a risk assessment before you start this investigation, so that you carry it out safely.

Tip: Canadian pondweed is not native to the UK, so it must be disposed of carefully after the experiment — it shouldn't be released into the environment.

The apparatus for the experiment should be set up as shown in Figure 2. The gas syringe should be empty at the start of the experiment. Sodium hydrogencarbonate releases carbon dioxide in solution — it is usually added to the water to make sure the plant has enough carbon dioxide (so that carbon dioxide concentration is not acting as a limiting factor.)

Figure 1: *Pondweed giving off oxygen bubbles as a by-product of photosynthesis.*

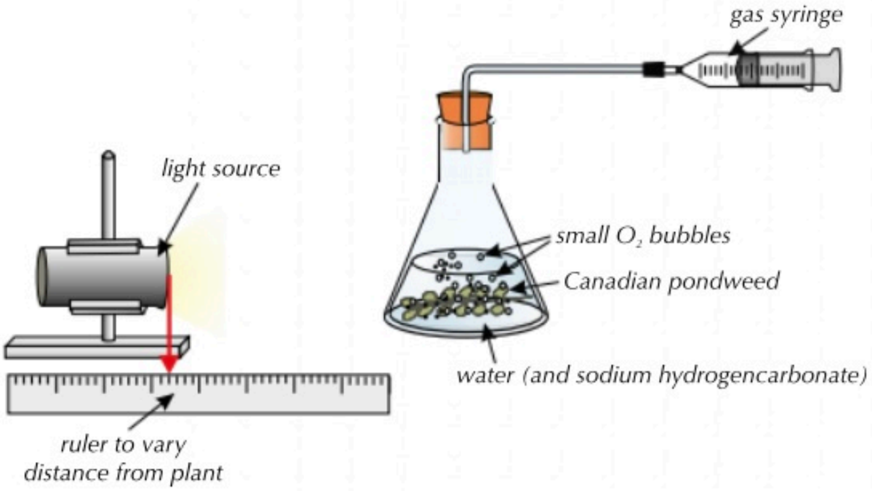

gas syringe
light source
small O_2 bubbles
Canadian pondweed
water (and sodium hydrogencarbonate)
ruler to vary distance from plant

Figure 2: *Diagram showing the experimental set up used to measure the rate of photosynthesis in water plants.*

You should repeat the experiment a few times with the light source at the same distance and calculate the mean volume of O_2 produced. Then you can repeat the whole procedure with the light source placed at different distances from the pondweed.

Tip: You can also investigate the rate of photosynthesis with algal balls, instead of pondweed. These are little balls of jelly which contain algae.

Controlling variables

In this experiment, you're investigating the effect of different light intensities on the rate of photosynthesis — the light intensity is the **independent variable**. The **dependent variable** (the variable you're measuring) is the amount of oxygen produced. You have to try to keep all the other variables constant, so that it's a fair test.

Tip: The independent variable is the variable that you change in an experiment — see page 10.

Examples

- If your plant's in a flask, keep the flask in a water bath to help keep the temperature constant.
- It's harder to control the carbon dioxide concentration. But if you add the same amount of sodium hydrogencarbonate to the same volume of water each time, it should mean that roughly the same amount of carbon dioxide is available to the plant in each experiment.

Tip: For more on designing investigations and controlling variables see pages 9-11.

Tip: The experiment can be modified to test the effect of temperature of carbon dioxide concentration too. Just remember to only change one variable at a time.

Calculating the rate of photosynthesis

You can compare the results at different light intensities by giving the rate of oxygen production as the volume of gas produced per unit time, e.g. $\text{cm}^3\ \text{min}^{-1}$.

To calculate the rate, just divide the total volume of gas that the plant produced by the time taken to produce it.

Example

A student measured the amount of oxygen produced by a piece of pondweed by collecting it in a gas syringe. After 5 minutes, 2.5 cm^3 of oxygen had been collected. Calculate the rate of oxygen production. Give your answer in $\text{cm}^3\ \text{min}^{-1}$.

Divide the volume of oxygen produced by the time taken:

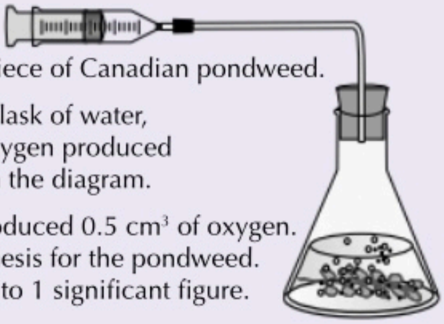
$$\text{Rate} = 2.5\ \text{cm}^3 \div 5\ \text{min} = \mathbf{0.5\ cm^3\ min^{-1}}$$

Tip: When you're working out a rate, you should always be dividing by time.

Practice Question — Application

Q1 A student set up an experiment to investigate the rate of photosynthesis using a piece of Canadian pondweed.

She placed the pondweed in a flask of water, and measured the amount of oxygen produced using a gas syringe, as shown in the diagram.



In 3 minutes, the pondweed produced 0.5 cm^3 of oxygen. Calculate the rate of photosynthesis for the pondweed. Give your answer in $\text{cm}^3\ \text{min}^{-1}$, to 1 significant figure.

Tip: There are other ways that you could carry out this experiment too. For example, instead of measuring the volume of oxygen produced, you could count the number of bubbles released by the plant in a set time.

Learning Objective:

- H Be able to explain how the rate of photosynthesis is directly proportional to light intensity and inversely proportional to the distance from a light source, including the use of the inverse square law calculation.

Specification Reference 6.6

4. The Inverse Square Law Higher

This can be a bit tricky to get your head around, but stick with it...

What is the inverse square law?

The rate of photosynthesis is **directly proportional** to light intensity. So when you increase the light intensity, the rate of photosynthesis increases at the same rate, and when you decrease the light intensity, the rate of photosynthesis decreases at the same rate.

When a plant is moved away from a light source (e.g. a lamp), the amount of light reaching the plant decreases — in other words, as the distance increases, the light intensity decreases. So both the light intensity and the rate of photosynthesis are **inversely proportional** to the distance from a light source.

Tip: H If two variables are proportional to each other, when one variable changes, the other will change at the same rate. Inverse proportion just means that as one variable increases, the other decreases at the same rate.

However, it's not quite as simple as that. It turns out that light intensity decreases in proportion to the square of the distance. This is called the **inverse square law** and is written out like this:

This is the 'proportional to' symbol.

Putting one over the distance shows the inverse.

$$\text{light intensity} \propto \frac{1}{\text{distance (d)}^2}$$

The distance is squared.

The inverse square law means that if you halve the distance, the light intensity will be four times greater and if you third the distance, the light intensity will be nine times greater. Likewise, if you double the distance, the light intensity will be four times smaller and if you treble the distance, the light intensity will be nine times smaller.

You can use $1/d^2$ as a measure of light intensity.

Example **Higher**

Use the inverse square law to calculate the light intensity when the lamp is 10 cm from the pondweed.

- Use the formula $\frac{1}{d^2}$: $\text{light intensity} = \frac{1}{d^2}$
- Fill in the values you know — you're given the distance, so put that in. $\text{light intensity} = \frac{1}{10^2}$
- Calculate the answer. $\frac{1}{10^2} = \mathbf{0.01\ a.u.}$

Tip: H a.u. stands for arbitrary units.

Practice Question — Application

Q1 A student is carrying out an experiment to study the effect of light intensity on the rate of photosynthesis. He places a lamp at different distances from samples of pondweed. Use the inverse square law to calculate the light intensity when the lamp is positioned:

a) 15 cm from the pondweed, b) 30 cm from the pondweed.

5. Transport in Plants

Like all living things, plants need transport systems to move substances around...

Learning Objectives:

- Be able to explain how the structures of the xylem and the phloem are adapted to their function in the plant, including:
  - living cells in the phloem using energy to transport sucrose around the plant.
  - lignified dead cells in the xylem transporting water and minerals through the plant.
- Be able to describe how sucrose is transported around the plant by translocation.
- Be able to explain how water and mineral ions are transported through the plant by transpiration.
- Be able to explain how the structure of the root hair cells is adapted to absorb water and mineral ions.

Specification References 6.7 – 6.10

Transport tissues in plants

Flowering plants have two separate types of tissue — phloem and xylem — for transporting substances around. Both types of tissue form ‘tubes’, which go to every part of the plant, but they are totally separate.

Phloem

Phloem tubes are made of columns of elongated living cells with small pores in the end walls to allow cell sap to flow through (see Figures 1 and 2). Cell sap is a liquid that's made up of the substances being transported and water.

Phloem tubes transport food substances (mainly dissolved sucrose) made in the leaves to the rest of the plant for immediate use (e.g. in growing regions) or for storage. The transport goes in both directions — from the leaves down to the roots, and from the roots up to the leaves. This process is called **translocation** and requires energy from respiration.

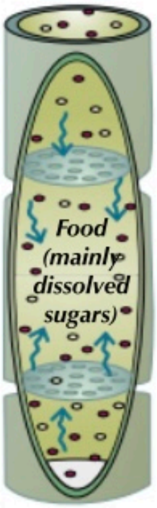


Figure 1: *Diagram showing the inside of a phloem tube.*

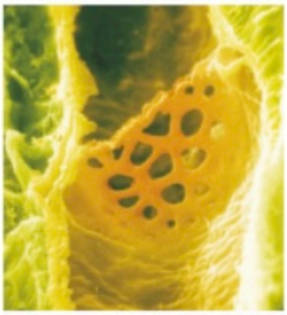


Figure 2: *Microscope image of the inside of a cut phloem tube — the small holes between the cells can be seen clearly.*

Xylem

Xylem tubes are made of dead cells joined end to end with no end walls between them and a hole down the middle (see Figures 3 and 4). They're strengthened with a material called lignin.

Xylem tubes carry water and mineral ions up the plant — from the roots to the stem and leaves. The movement of water from the roots, through the xylem and out of the leaves is called the **transpiration stream** (see next page).

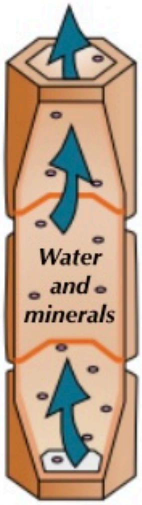


Figure 3: *Diagram showing the inside of a xylem tube.*

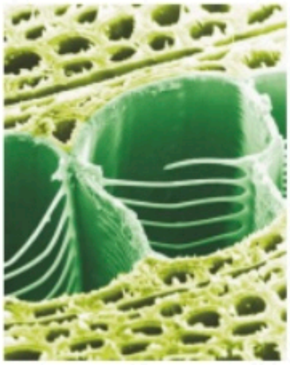


Figure 4: *Microscope image showing a cut xylem tube (dark green).*

Tip: Cells in the root (called root hair cells) take up water from the soil by osmosis, and take up mineral ions by active transport. There's more information about how they're adapted for this on page 209.

The transpiration stream

Transpiration is the loss of water from a plant's surface. It is caused by the evaporation and diffusion (see p.48) of water from surface of the plant (usually the leaves). The transpiration stream is the movement of water and mineral ions through a plant from the roots to the leaves.
It happens like this:

1. Water from inside a leaf evaporates and diffuses out of the leaf, mainly through the stomata (tiny holes found mainly on the lower surface of the leaf) — see Figure 5.

2. This creates a slight shortage of water in the leaf, and so more water is drawn up from the rest of the plant through the xylem vessels to replace it.

3. This in turn means more water is drawn up from the roots, and so there's a constant transpiration stream of water through the plant.

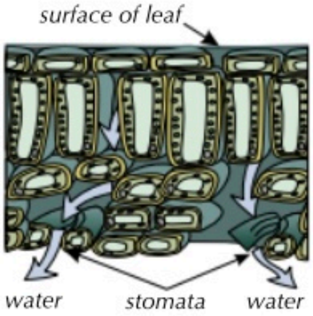


Figure 5: *Cross-section of a leaf showing how water moves out during transpiration.*

The transpiration stream carries mineral ions that are dissolved in the water along with it.

The transpiration stream is shown in Figure 6.

Tip: The rate of transpiration depends on the conditions in the plant's environment. Transpiration happens fastest in bright, hot and dry conditions where the air flow around the leaves is good, because this is when evaporation happens fastest — see page 210 for more.

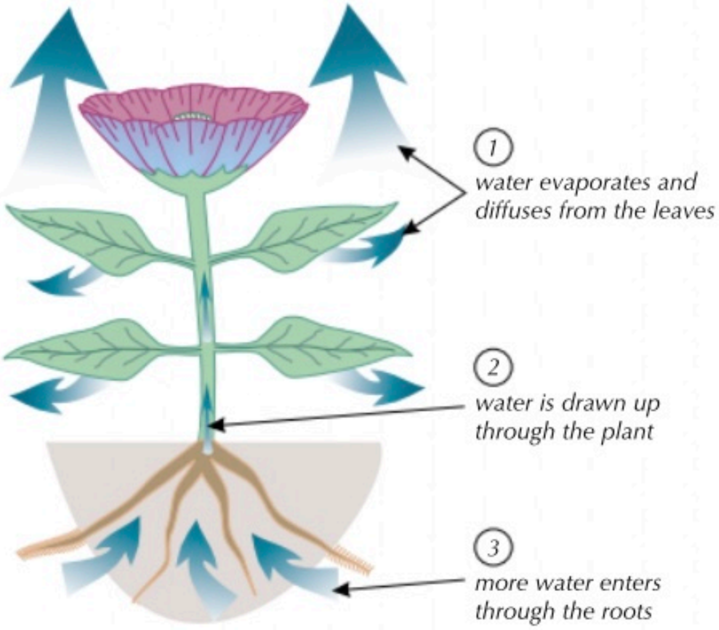

1
water evaporates and diffuses from the leaves
2
water is drawn up through the plant
3
more water enters through the roots

Figure 6: *Diagram showing how water moves through a plant in the transpiration stream.*

Transpiration is just a side-effect of the way leaves are adapted for photosynthesis. They have to have stomata in them so that gases can be exchanged easily (see page 211). Because there's more water inside the plant than in the air outside, the water escapes from the leaves through the stomata by diffusion.

Root hair cells

The cells on the surface of plant roots grow into "hairs", which stick out into the soil (see Figure 7). Each branch of a root will be covered in millions of these microscopic hairs.

The hairs give the plant a large surface area for absorbing water and mineral ions from the soil. The concentration of mineral ions is usually higher in the root hair cells than in the soil around them, so mineral ions are absorbed by active transport (see page 51). There is normally more water in the soil than in the roots, so water is absorbed by osmosis (see pages 49-50).

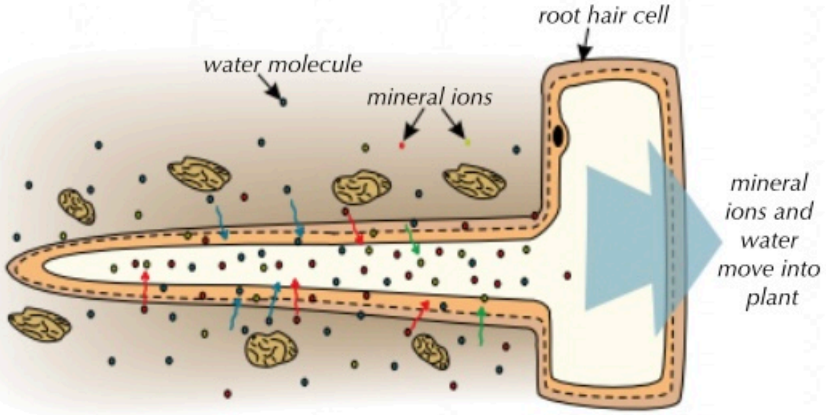


Figure 7: *Diagram to show the absorption of water and mineral ions by a root hair cell.*

Practice Questions — Fact Recall

Q1 What is transported in phloem tubes?

Q2 Describe the structure of the phloem tubes.

Q3 Give two substances that are transported in xylem tubes.

Q4 Explain how the transpiration steam works to move water through a plant.

Q5 Explain how the shape of root hair cells help a plant to absorb water and mineral ions through its roots.

6. Transpiration and Stomata

How quickly transpiration takes place is affected by several factors...

Learning Objectives:

- Be able to explain the effect of environmental factors on the rate of water uptake by a plant, including light intensity, air movement and temperature.
- Be able to demonstrate an understanding of rate calculations for transpiration.
- Be able to describe the structure and function of the stomata.

Specification References
6.9, 6.12, 6.13

Factors affecting transpiration rate

Transpiration rate is affected by three main environmental factors:

Light intensity

The brighter the light, the greater the transpiration rate. Stomata begin to close as it gets darker. Photosynthesis can't happen in the dark, so they don't need to be open to let CO_2 in. When the stomata are closed, very little water can escape.

Temperature

The warmer it is, the faster transpiration happens. When it's warm, the water particles have more energy to evaporate and diffuse out of the stomata.

Air flow

The better the air flow around a leaf (e.g. stronger wind), the greater the transpiration rate.

If air flow around a leaf is poor, the water vapour just surrounds the leaf and doesn't move away. This means there's a high concentration of water particles outside the leaf as well as inside it, so diffusion doesn't happen as quickly.

If there's good air flow, the water vapour is swept away, maintaining a low concentration of water in the air outside the leaf. Diffusion then happens quickly, from an area of higher concentration to an area of lower concentration.

Tip: Wet clothes dry as water evaporates from the fabric. You wouldn't expect clothes hung out in the garden to dry very quickly on a cold, wet day — so don't expect evaporation from a plant to be quick under those conditions either.

Investigating transpiration rate

You can estimate the rate of transpiration by measuring the uptake of water by a plant using a **potometer**. This is because you can assume that water uptake by the plant is directly related to water loss by the leaves (transpiration). Figure 1 shows the apparatus you'll need.

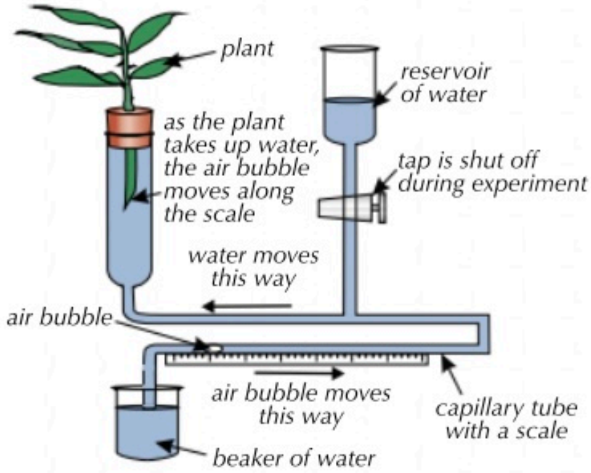

plant
reservoir of water
as the plant takes up water, the air bubble moves along the scale
tap is shut off during experiment
water moves this way
air bubble
air bubble moves this way
capillary tube with a scale
beaker of water

Figure 1: *A potometer — apparatus for measuring the uptake of water by a plant.*

Tip: You can use a potometer to estimate how light intensity, temperature or air flow around the plant affect the transpiration rate. Just remember to only change one variable at a time and control the rest to make it a fair test.

To investigate the rate of transpiration, set up the apparatus as in Figure 1, and then record the starting position of the air bubble. Start a stopwatch and record the distance moved by the bubble per unit of time, e.g. per hour. Keep the conditions constant throughout the experiment, e.g. the temperature and air humidity. Calculating the speed of the air bubble movement gives an estimate of the transpiration rate.

Tip: It's quite tough to set up a potometer. See page 319 for some tips.

Estimating the rate of transpiration

You can use the data you collect in your experiment to estimate the rate of transpiration. Take a look at this example:

Tip: The faster the transpiration rate, the faster the water uptake by the plant.

Example

A potometer was set up to estimate the rate of transpiration of a plant. In 60 minutes, the bubble in the potometer moved 6.6 cm. Calculate the rate of transpiration. Give your answer in mm min^{-1}.

1. First, convert 6.6 cm into mm:

   $6.6 \times 10 = 66$ mm

2. Then divide the distance moved by the time taken:

   $66 \div 60 =$ **1.1 mm min^{-1}**

Tip: Rates of transpiration can also be given in mm^3 min^{-1}, but this requires a bit more maths to find the actual volume of water that the plant has taken up.

Stomata and guard cells

Stomata are tiny pores on the surface of a plant. They're mostly found on the lower surface of leaves. Stomata allow CO_2 and oxygen to diffuse directly in and out of a leaf. They also allow water vapour to escape during transpiration.

Tip: Stoma is the singular word, stomata is the plural.

Two guard cells surround each stoma. Guard cells have a kidney shape — having this shape helps to open and close the stomata.

- When the plant has lots of water, the guard cells fill with water and go turgid (swollen with water). This opens the stomata so gases can be exchanged for photosynthesis (see Figure 2).
- When the plant is short of water, the guard cells lose water and become flaccid (limp), closing the stomata (see Figure 2). This helps stop too much water vapour escaping.

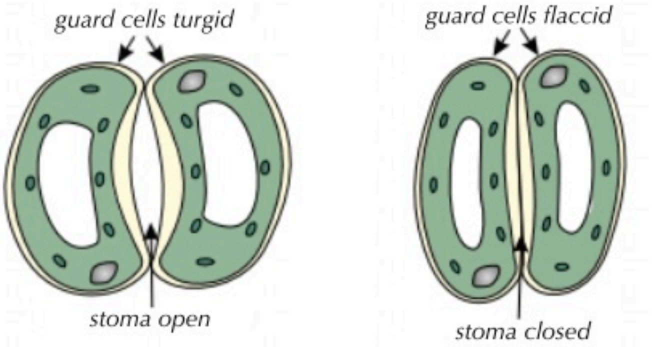


Figure 2: *Diagram showing how guard cells open and close a stoma.*

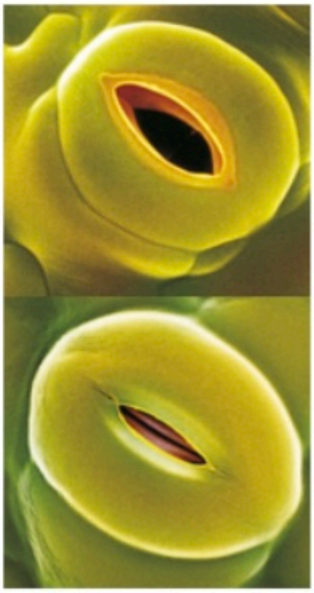


Figure 3: *An open stoma (top) and a closed stoma (bottom).*

Guard cells have other adaptations besides their shape which help with their roles in gas exchange and controlling water loss within a leaf:

- They have thin outer walls and thickened inner walls, which helps to make the opening and closing mechanism work.
- They're sensitive to light, so they can close the stomata at night to save water without losing out on photosynthesis.

You usually find more stomata on the undersides of leaves than on the top. The lower surface is shaded and cooler — so less water is lost through the stomata than if they were on the upper surface.

Practice Questions — Fact Recall

Q1 What is the effect of increasing light intensity on the rate of transpiration?

Q2 Potometers can be used to estimate the rate of transpiration. What does a potometer actually measure?

Q3 a) Name the cells that control the size of the stomata.

b) Explain how these cells close the stomata.

Practice Question — Application

Q1 A student used a potometer to measure the effect that changing the temperature had on the rate of transpiration of a plant cutting.

For each temperature she tested, she kept the equipment at that temperature and measured the distance that the air bubble in the potometer moved in 30 minutes. She repeated the experiment at three different temperatures. Her results are shown below.

Temperature / °C	Distance moved by bubble / mm
10	26
15	31
20	37

Tip: Rate is measured as a given quantity per unit time. In Q1a, it's a measure of distance divided by time.

a) Calculate the rate of transpiration of the plant in mm min^{-1} at:

i) 10 °C

ii) 15 °C

b) Explain why the bubble moved a greater distance when the plant was kept at 20 °C than when it was kept at 10 °C.

7. Adaptations of Leaves and Plants

You've got to know how a leaf is adapted for its job, and how some plants have adapted to live in extreme environments (like very hot places).

Learning Objectives:

- Be able to explain how the structure of a leaf is adapted for photosynthesis and gas exchange.
- Be able to explain how plants are adapted to survive in extreme environments including the effect of leaf size and shape, the cuticle and stomata.

Specification References 6.11B, 6.14B

Leaf structure

The leaf is an organ made up of several types of tissue. Leaves contain epidermal, mesophyll, xylem and phloem tissues (see Figures 1 and 2).

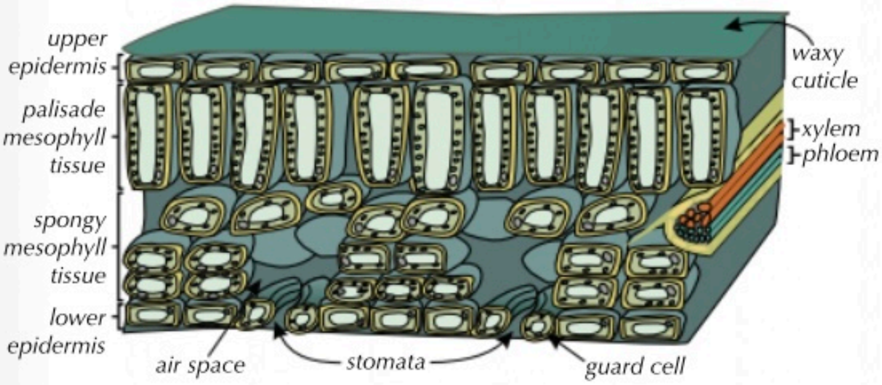


Figure 1: *Diagram showing a cross-section of a typical plant leaf.*

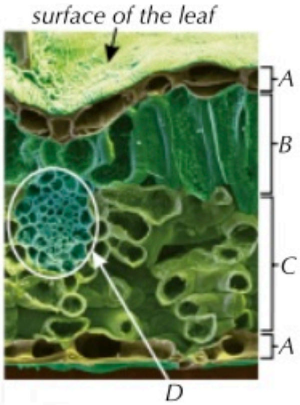


Figure 2: *A cross-section through a leaf, seen under a microscope. It shows the epidermal tissue (A), palisade mesophyll tissue (B), spongy mesophyll tissue (C) and xylem and phloem tissue (D).*

You need to know how the leaf is adapted to make photosynthesis efficient:

- The epidermal tissues of the leaf are covered with a thick waxy cuticle, which helps to reduce water loss from the leaf by evaporation.
- The upper epidermis is transparent so that light can pass through it to the palisade layer.
- The cells in the palisade mesophyll tissue contain lots of chloroplasts (the little structures where photosynthesis takes place). They're near the top of the leaf where they can get the most light.
- The xylem and phloem form a network of vascular bundles, which deliver water and other nutrients to the entire leaf and take away the glucose produced by photosynthesis. They also help support the structure.
- Leaves are broad, so there is a large surface area exposed to light, which is needed for photosynthesis.

You also need to know how the leaf is adapted for efficient gas exchange:

- The lower epidermis is full of little holes called stomata, which let carbon dioxide diffuse directly into the leaf. The opening and closing of stomata is controlled by guard cells in response to environmental conditions.
- The air spaces in the spongy mesophyll tissue increase the rate of diffusion of gases through the leaf.

Exam Tip
If you're struggling to remember where the different tissues are in a leaf, think of it as epidermis is external and mesophyll is in the middle.

Tip: See pages 211-212 for more on stomata and guard cells.

Plant adaptations for extreme environments

Some plants are adapted to live in extreme environments, e.g. places that are very hot or very dry (like deserts). Adaptations tend to affect the size and shape of the plant's leaves, its cuticle, and the number and position of its stomata.

For example, plants living in deserts (like cacti) tend to have the following adaptations, which help them to conserve water:

- Some plants have small leaves, or spines instead of leaves, to reduce the surface area for water loss by evaporation. Spines also help to stop animals eating the plant to get water.
- Some plants have curled leaves, or hairs on the surface of leaves. These reduce air flow close to the leaf, trapping water vapour near the surface and reducing diffusion from the leaf to the air. (Spines also reduce air flow near the surface of the plant and so do a similar job.)
- Many plants have leaves with a thick waxy cuticle, which reduces water loss by evaporation.
- The stems of some plants are thick and fleshy, to help them store water.
- A lot of water can be lost by evaporation from the stomata. To combat this, some plants have few stomata, or stomata that only open at night.
- Many desert plants have their stomata sunken in pits. This makes the stomata lower than the surface of the leaf, which reduces air flow close to the stomata. This reduces water loss in the same way as curled leaves or hairs.

Tip: Adaptations are features that help an organism to survive in its environments.

Figure 3: *Most cacti have spines, which help to reduce water loss and prevent animals from eating them.*

Tip: Marram grass and cacti are good examples of plants that are adapted for life in extreme environments.

Tip: Hot deserts aren't the only extreme environments plants are adapted to living in. For example, arctic plants have adapted to carry out photosynthesis even when the temperature is very low. They have small leaves to reduce water loss too, and grow close to the ground to prevent wind damage.

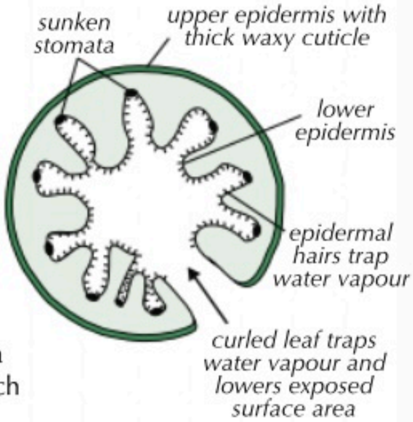

sunken stomata
upper epidermis with thick waxy cuticle
lower epidermis
epidermal hairs trap water vapour
curled leaf traps water vapour and lowers exposed surface area

Figure 4: *Adaptations of a leaf that help reduce water loss.*

Practice Questions — Fact Recall

Q1 Describe the role of the waxy cuticle on a plant leaf.

Q2 Explain why the upper epidermis of a leaf is transparent.

Q3 The palisade mesophyll tissue is the part of the leaf where most of the leaf's photosynthesis takes place. Describe two features of the palisade mesophyll tissue that help a leaf to photosynthesise efficiently.

Q4 What is the function of the air spaces in spongy mesophyll tissue?

Q5 Some desert plants have spines instead of leaves. Explain how this adaptation helps them to conserve water.

8. Plant Hormones

Like animals, plants have to respond to stimuli. Plant hormones control and coordinate the growth response of plants to light and gravity.

Learning Objective:

- Be able to explain how plant hormones control and coordinate plant growth and development, including the role of auxins in phototropisms and gravitropisms.

Specification Reference 6.15B

A plant's needs

Plants need to be able to detect and respond to **stimuli** (changes in the environment) in order to survive:

Examples

- Plants need light to make their own food. Plants can sense light, and grow towards it in order to maximise the amount of light they receive.
- Plants can sense and respond to gravity. This makes sure that their roots and shoots grow in the right direction.

Auxin

Auxin is a plant hormone that controls growth near the tips of shoots and roots. It moves through the plant in solution and controls the growth of a plant in response to different stimuli.

Auxin controls:

- **Phototropism** — plant growth in response to light.
- **Gravitropism** (also known as **geotropism**) — plant growth in response to gravity.

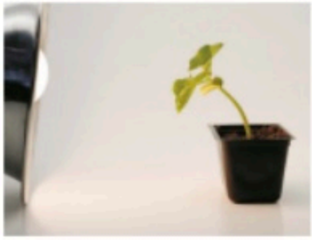


Figure 1: *A plant displaying phototropism — its shoot is growing towards the light.*

Auxin is produced in the tips of shoots and moves backwards to stimulate the cell elongation process, which occurs in the cells just behind the tips (see Figure 2).

Auxin is also produced in the tips of roots, but in the roots it moves backwards and inhibits cell elongation in the cells behind the tips.

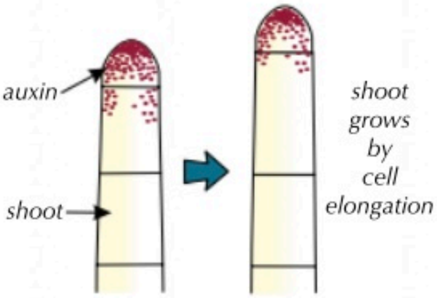


Figure 2: *Auxin release from the tips of shoots results in cell elongation and shoot growth.*

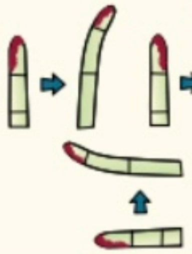
Tip: Cell elongation just means that the cells of the plant get bigger (longer).

Tip: If the tip of a shoot is removed, no auxin is produced and the shoot may stop growing.

Shoot and root growth

As you saw above, extra auxin promotes growth in the shoot but inhibits growth in the root. This, coupled with the unequal distribution of auxin in the shoot or root tip, can affect the direction that shoot and roots grow in. This produces the results seen on the next two pages.

Tip: In shoots, more auxin on one side means that the cells on that side will grow faster. This will cause the plant to bend away from that side, e.g.



Tip: If a part of a plant grows towards a stimulus, it is growing positively with respect to that stimulus. If it grows away from a stimulus, it is growing negatively with respect to that stimulus.

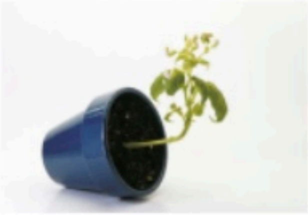
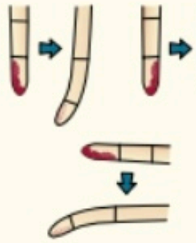


Figure 4: *A plant displaying gravitropism — its shoots are growing away from gravity.*

Tip: In roots, more auxin on one side means that the cells on that side will grow slower. This will cause the plant to bend towards that side, e.g.



1. Shoots grow towards light

When a shoot tip is exposed to light, more auxin accumulates on the side that's in the shade than the side that's in the light. This makes the cells grow (elongate) faster on the shaded side, so the shoot bends towards the light (see Figure 3). As shoots grow towards light, they are **positively phototropic**.

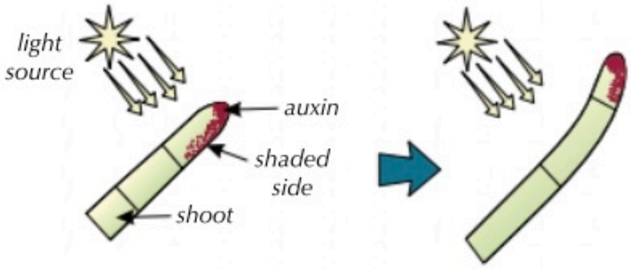


Figure 3: *Diagram to show how auxin causes shoot growth towards the light.*

By bending towards the light, the shoot will be able to absorb more light for photosynthesis, which enables the plant to grow. Shoots growing completely in the dark will be tall and spindly — the auxin in the tips makes them elongate quickly on all sides. A tall shoot has a better chance of finding light.

2. Shoots grow away from gravity

When a shoot is growing sideways, gravity produces an unequal distribution of auxin in the tip, with more auxin on the lower side. This causes the lower side to grow faster, bending the shoot upwards, as shown in Figure 5. Shoots are **negatively gravitropic**.

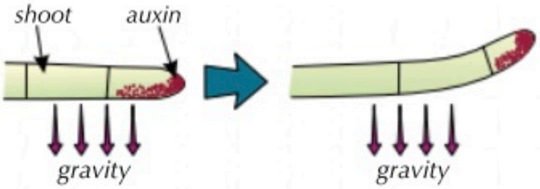


Figure 5: *Diagram to show how auxin causes shoot growth away from gravity.*

The distribution of auxin in response to gravity means that the shoot should always grow in the right direction (i.e. upwards), even in the absence of light.

3. Roots grow towards gravity

When a root is growing sideways, more auxin will accumulate on its lower side. In a root the extra auxin inhibits growth. This means the cells on top elongate faster, and the root bends downwards (see Figure 6). This process is known as **positive gravitropism**.

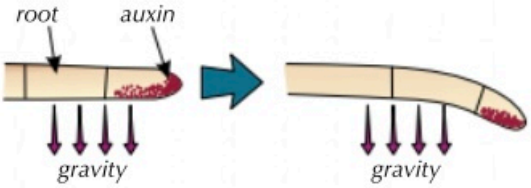


Figure 6: *Diagram to show how auxin causes root growth towards gravity.*

4. Roots grow away from light

If a root starts being exposed to some light, more auxin accumulates on the shaded side. The auxin inhibits cell elongation on the shaded side, so the root bends downwards, back into the ground (see Figure 7). This is known as **negative phototropism**.

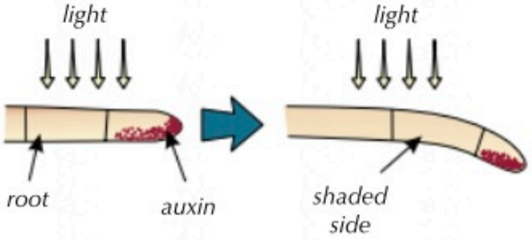


Figure 7: *Diagram to show how auxin causes root growth away from light.*

Roots that are deep underground aren't exposed to light. They grow downwards due to positive gravitropism.

Investigating plant growth responses

You can investigate the effect of light on the growth of cress seeds like this:

1. Put 10 cress seeds into a Petri dish lined with moist filter paper.
2. Surround the Petri dish with black card. A simple way to do this is to make a box out of black card and put the dish in that.
3. Cut a hole in one side of the card only.
4. Shine a light into the box through the hole (see Figure 8).
5. Leave your cress seeds alone for one week until you can observe their response — you'll find the seedlings grow towards the light. You can even measure the angle they're growing at.

Tip: Light should only be able to reach the dish through the hole because the card will stop light entering from other directions.

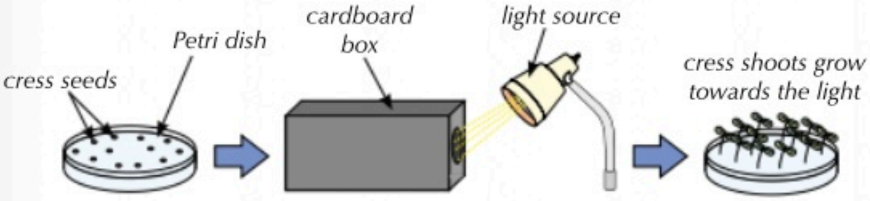


Figure 8: *Diagram to show an experiment to investigate the effect of light on the growth of cress seeds.*

Practice Questions — Fact Recall

Q1 What is gravitropism?

Q2 Explain how auxin causes a plant shoot to grow towards light.

Q3 Explain how plant roots grow in response to gravity.

Learning Objective:

- H Be able to describe the commercial uses of auxins, gibberellins and ethene in plants, including:
  - H auxins in weedkillers and rooting powders;
  - H gibberellins in germination, fruit and flower formation and the production of seedless fruit;
  - H ethene in fruit ripening.

Specification Reference 6.16B

9. Commercial Uses of Plant Hormones Higher

Plant hormones can be extracted and used by people in agriculture (farming) or horticulture (gardening). Artificial versions can also be made. You need to know about the uses of auxins, gibberellins and ethene.

Auxins

Auxins are useful for controlling plant growth. They are used for:

1. Selective weedkillers

Most weeds growing in fields of crops or in a lawn are broad-leaved, in contrast to grasses and cereals which have very narrow leaves. Selective weedkillers have been developed using auxins, which only affect the broad-leaved plants. The weedkillers disrupt their normal growth patterns, which soon kills them, whilst leaving the grass and crops untouched.

Tip: H Weeds compete with crops for resources, e.g. light and nutrients. If you remove the weeds, you remove the competition — so the crop will have more resources. This should mean that the crop grows more and produces a bigger yield. There's more on competition on pages 283-284.

2. Growing from cuttings with rooting powder

A cutting is part of a plant that has been cut off it, like the end of a branch with a few leaves on it. Normally, if you stick cuttings in the soil they won't grow, but if you add **rooting powder,** which contains auxins, they will produce roots rapidly and start growing as new plants. This enables growers to produce lots of clones (exact copies) of a really good plant very quickly.

Gibberellins

Gibberellins are another type of plant growth hormone. They stimulate seed germination (the growth of a seed into a plant), stem growth and flowering. Uses include:

1. Controlling flower and fruit formation

Gibberellins can be used to make plants flower earlier than they would usually do so, or under conditions in which they wouldn't usually flower (e.g. when it's warmer than usual).

Gibberellins can also be used to reduce flower formation. Since fruit grows from pollinated flowers, this can improve fruit quality.

Example **Higher**

Apricot trees often produce too many flowers. This causes too many fruits to form — the tree can't support them all and they grow quite small. Fewer flowers means fewer fruits, which are able to grow to large sizes.

2. Controlling seed germination

Lots of seeds won't germinate until they've been through certain conditions (e.g. a period of cold or of dryness). Seeds can be treated with gibberellins to make them germinate at times of year that they wouldn't normally. It also helps to make sure all the seeds in a batch germinate at the same time.

3. Producing seedless fruit

Fruit (with seeds in the middle) normally only grows on flowering plants which have been pollinated by insects. If the flower doesn't get pollinated, the fruit and seeds don't grow.

If plant hormones such as gibberellins are applied to the unpollinated flowers of some types of plant, the fruit will grow but the seeds won't. Some seedless citrus fruits can be grown this way.

Ethene

Ethene is a ripening hormone produced by aging parts of a plant. It influences the growth of the plant by controlling cell division. It also stimulates enzymes that cause fruit to ripen.

Tip: **H** Some fruit will produce more ethene as it ripens.

Commercially, it can be used to speed up the ripening of fruits — either while they are still on the plant, or during transport to the shops. This means that fruit can be picked while it's still unripe (and therefore firmer and less easily damaged). Ethene gas is then added to the fruit on the way to the supermarket so that it will be perfect just as it reaches the shelves.

Ripening can also be delayed while the fruit is in storage by adding chemicals that block ethene's effect on the fruit or reduce the amount of ethene that the fruit can produce. Alternatively, some chemicals can be used that react with ethene to remove it from the air.

Practice Questions — Fact Recall

Q1 Name the type of plant hormone that is found in rooting powders.

Q2 Name the type of plant hormone that controls seed germination.

Q3 What effect does ethene have on fruit?

Figure 1: *A gardener using rooting powder when planting cuttings.*

Practice Question — Application

Q1 Dan grows plants for a garden centre. He is trying to find the best rooting powder to use for his cuttings. Using the same type of plant, he grows 50 cuttings in rooting powder A, 50 in rooting powder B and 50 without rooting powder. He grows all the cuttings under the same conditions. His results are shown in the table below.

		Powder A	Powder B	No powder
Average increase in root length (mm)	**After 1 week**	8	10	6
	After 2 weeks	17	19	14
	After 3 weeks	24	28	20

a) From these results, what can you conclude about which rooting powder, A or B, is the best to use? Explain your answer.

b) Suggest why Dan grew some of the cuttings without using rooting powder.

Topic 6 Checklist — Make sure you know...

Photosynthesis

☐ That photosynthesis is a process used by green plants and algae that converts carbon dioxide and water into glucose and oxygen.

☐ That plants use some of the glucose produced during photosynthesis to build up their biomass.

☐ That plants are responsible for producing most of the food and biomass in the food chain.

☐ That photosynthesis is an endothermic reaction that requires light energy.

☐ That photosynthesis takes place in chloroplasts.

☐ The word equation and symbol equation for photosynthesis.

Limiting Factors in Photosynthesis

☐ That photosynthesis requires light, a suitable temperature and carbon dioxide to occur.

☐ How light intensity, carbon dioxide concentration and temperature act as limiting factors on the rate of photosynthesis.

☐ **H** How light intensity, carbon dioxide concentration and temperature all act together to control the rate of photosynthesis in a plant.

Investigating the Rate of Photosynthesis

☐ How to carry out an experiment to investigate the effect of light intensity on the rate of photosynthesis (Core Practical).

The Inverse Square Law

☐ **H** That the rate of photosynthesis is directly proportional to light intensity.

☐ **H** That the rate of photosynthesis is inversely proportional to the distance from a light source.

☐ **H** How to use the inverse square law in calculations involving light intensity and distance from an object (such as a plant).

Transport in Plants

☐ That phloem tubes are made of elongated living cells, which have pores (holes) between them to allow cell sap to pass through.

☐ That the phloem carries sucrose and other substances between the leaves and the rest of the plant (including the roots) in a process called translocation.

☐ That translocation requires energy from respiration.

☐ That xylem tubes are made of dead cells with no end walls between them.

cont...

☐ That xylem tubes are strengthened with lignin.

☐ How the xylem carries water and mineral ions from the roots to the leaves in the transpiration stream.

☐ How the root hair cells of plants are adapted to efficiently absorb mineral ions and water from the soil.

Transpiration and Stomata

☐ How light intensity, temperature and air flow affect the rate of transpiration.

☐ How to estimate the rate of transpiration from the results of an experiment to investigate the water uptake of a plant.

☐ How the stomata (pores) on a leaf are opened and closed by the guard cells.

☐ How the stomata and guard cells are adapted for their role in gas exchange in a plant.

Adaptations of Leaves and Plants

☐ That the leaf of a plant contains epidermal, mesophyll, xylem and phloem tissues.

☐ How a leaf is adapted for its function as the main site of photosynthesis in a plant.

☐ How a leaf is adapted for its function as the main site of gas exchange in a plant.

☐ That some plants have adapted to live in extreme conditions, such as deserts.

☐ Examples of the adaptations that plants possess that allow them to live in extreme environments.

Plant Hormones

☐ That auxin is a hormone produced by plants that controls the growth of the shoots and roots.

☐ That phototropism is plant growth in response to light.

☐ That gravitropism is plant growth in response to gravity.

☐ The meaning of the terms ‘negative’ and ‘positive’ with respect to phototropism and gravitropism.

☐ How auxin affects how the growth of shoots and roots in response to light and gravity.

Commercial Uses of Plant Hormones

☐ **H** How auxins are used as selective weedkillers and in rooting powder.

☐ **H** How gibberellins can control flower and fruit formation and seed germination.

☐ **H** How gibberellins can be used to produce seedless fruit.

☐ **H** How the ripening of fruit can be control using ethene.

Exam-style Questions

1 Tim read the following information in a science magazine:

> You can measure the rate of photosynthesis in plants by doing the following:
>
> Cut discs from a plant leaf. Put them into dilute sodium hydrogencarbonate solution (which serves as a source of carbon dioxide). Put the solution and leaf discs in a syringe and then remove all the air from the syringe — this removes any gases from the air spaces in the leaf, which will cause the leaf discs to sink.
>
> Then put the syringe containing the leaf discs under a light source. As the leaf discs photosynthesise, their cells produce oxygen. The oxygen will fill the air spaces in the leaf — with enough oxygen in the air spaces they'll begin to float. You can use the time this takes as a measure of the rate of photosynthesis.

(a) Where in a plant cell does photosynthesis take place?

(1 mark)

(b) Complete the word equation for photosynthesis:

carbon dioxide + ... ⟶ .... + oxygen

(1 mark)

Tim decided to use this experiment to investigate the effect of light intensity on the rate of photosynthesis. He conducted the experiment at three different light intensities. For each light intensity he cut 10 equally sized discs from a leaf, and set up the experiment as described in the magazine. He then timed how long it took for all of the leaf discs to float to the surface in the syringe. His results are shown in **Figure 1**.

Light intensity	Time it took for all discs to float (minutes)
A	18
B	9
C	11

Figure 1

(c) Which light intensity do you think was the highest, **A**, **B** or **C**? Explain your answer.

(3 marks)

(d) Tim thinks that if he keeps increasing the light intensity, he will keep increasing the rate of photosynthesis. Is he right? Explain your answer.

(3 marks)

(e) Tim conducts the experiment again at light intensity **C**. This time, instead of using sodium hydrogencarbonate solution, he uses the same volume of distilled water. Would you expect it to take more or less than 11 minutes for all of the discs to float? Explain your answer.

(2 marks)

2 **Figure 2** shows a cross-section through a leaf.

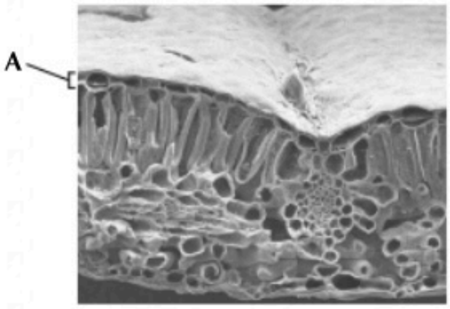


Figure 2

(a) What name is given to the layer of tissue labelled **A** in **Figure 2**?

(1 mark)

(b) Some of the cells in the photograph contain lots of chloroplasts.
What plant tissue are these cells part of? Explain your answer.

(2 marks)

3 Desert plants are adapted for life in hot, dry conditions.
Like most plants, they exchange gases through their stomata.

Suggest and explain how the following adaptations help plants to survive in desert conditions:

(a) Stomata are kept closed during the day, when it is hot and dry, and only opened at night, when it is cool.

(3 marks)

(b) Stomata are located in sunken pits.
The pits trap water vapour close to the surface of the leaf.

(2 marks)

4 Plant hormones have lots of uses in farming.

(a) A farmer has a greenhouse containing tomato plants that are about to come into flower. She wants to use them to produce seedless tomatoes.

Suggest how she could use a plant hormone to produce seedless tomatoes from the tomato plants.

(1 mark)

(b) A farmer notices that weeds have started to grow in the field with his wheat plants.
Explain how he could use auxins to selectively kill the weeds.

(2 marks)

(c) A company that grows tomatoes picks them while they are unripe.
The tomatoes are then transported and ripened before sale.
Name a plant hormone that could be used to ripen the tomatoes.

(1 mark)

Learning Objective:

- Be able to describe where hormones are produced and how they are transported from endocrine glands to their target organs, including the pituitary gland, thyroid gland, pancreas, adrenal glands, ovaries and testes.

Specification Reference 7.1

1. Hormones

Along with the nervous system (see pages 69-71) hormones allow us to react to changes in the environment and in our bodies. Hormones are secreted by the glands of the endocrine system.

What are hormones?

Hormones are chemical molecules released directly into the blood to regulate bodily processes. They are carried in the blood plasma (the liquid part of the blood) to other parts of the body, but only affect particular cells in particular organs (called **target organs**). Hormones control things in organs and cells that need constant adjustment.

Here's a definition of hormones:

> Hormones are chemical messengers which travel in the blood to activate cells in target organs.

The endocrine system

Hormones are produced in (and secreted by) various glands, called **endocrine glands**. These glands make up the endocrine system.

The endocrine system uses hormones to react to changes in the environment or changes inside the body.

Endocrine glands

There are many glands in the endocrine system, including:

- The **pituitary gland** — this produces many hormones that regulate body conditions. It is sometimes called the 'master gland' because these hormones act on other glands, directing them to release hormones that bring about change.
- The **thyroid gland** — this produces thyroxine, which is involved in regulating things like the rate of metabolism, heart rate and temperature (see p.227).
- The **pancreas** — this produces insulin, which is used to regulate the blood glucose level (see page 238).
- The **adrenal glands** — these produce adrenaline, which is used to prepare the body for a 'fight or flight' response (see page 227).

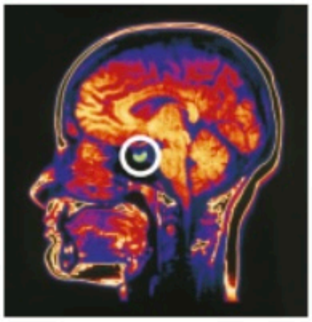
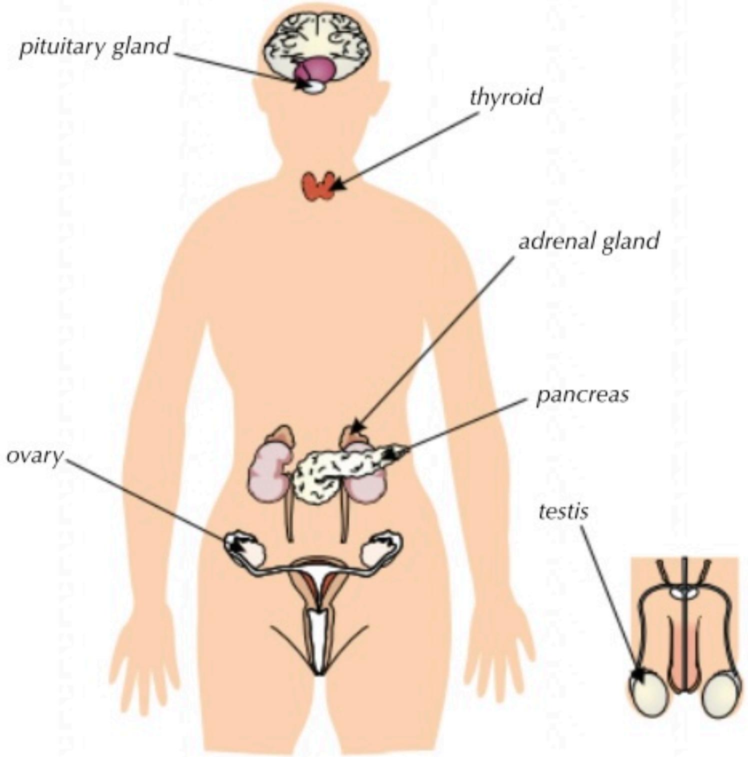


Figure 1: *Scan of the brain. The pituitary gland (green structure) is circled in white.*

- The **ovaries** (females only) — these produce oestrogen, which is involved in the menstrual cycle (see pages 229-231).
- The **testes** (males only) — these produce testosterone, which controls puberty and sperm production in males.

Exam Tip
Make sure you know which gland produces which hormone. Some of their names give you clues — the thyroid gland produces thyroxine, the adrenal glands produce adrenaline, the ovaries produce oestrogen and the testes produce testosterone.



Exam Tip
These are the glands you need to learn for the exam. There are loads more glands in the body though, each doing its own thing.

Tip: Testis is the singular of testes.

Figure 2: *Diagram showing the location of some of the endocrine glands.*

Comparing nerves and hormones

As hormones are carried in the blood, they tend to travel around the body relatively slowly (compared to nervous impulses anyway). They also tend to have relatively long-lasting effects. Hormones and nerves do similar jobs in the body, but with a few differences. These are summarised in Figure 3.

Tip: There's more about the nervous system on pages 69-71.

Nerves	Hormones
Fast action	Slower action
Act for a short time	Act for a long time
Acts on a very precise area	Acts in a more general way

Figure 3: *Table summarising the differences between nerves and hormones.*

If you're not sure whether a response is nervous or hormonal, have a think...

- If the response is really quick, it's probably nervous.
  Some information needs to be passed to effectors (muscles or glands) really quickly (e.g. pain signals, or information from your eyes telling you about a car heading your way), so it's no good using hormones to carry the message — they're too slow.
- If a response lasts for a long time, it's probably hormonal.
  For example, when you get a shock, a hormone called adrenaline is released into the body (causing the 'fight or flight' response, where your body is hyped up ready for action). You can tell it's a hormonal response (even though it kicks in pretty quickly) because you feel a bit wobbly for a while afterwards.

Exam Tip
Try to learn to spell difficult words like 'pituitary'. It'll help to make sure the examiner knows what you're talking about.

Practice Questions — Fact Recall

Q1 How are hormones carried around the body?

Q2 True or false? A particular hormone will have an effect on all organs.

Q3 What are hormones secreted from?

Q4 Name a hormone secreted from the testes.

Q5 Which produces a faster response — nerves or hormones?

2. Adrenaline and Thyroxine Higher

Adrenaline and thyroxine are both pretty useful hormones for us humans.

Adrenaline

Adrenaline is a hormone released by the **adrenal glands** (found just above the kidneys — see Figure 2 on page 225).

It is released in response to stressful or scary situations. Your brain detects fear or stress and sends nervous impulses to the adrenal glands, which respond by secreting adrenaline. Adrenaline gets the body ready for 'fight or flight' — in other words, standing your ground in the face of a threat (e.g. a predator) or bravely running away. It does this by triggering mechanisms that increase the supply of oxygen and glucose to cells.

Examples **Higher**

- Adrenaline binds to specific receptors in the heart. This causes the heart muscle to contract more frequently and with more force, so heart rate and blood pressure increase. This increases blood flow to the muscles, so the cells receive more oxygen and glucose for increased respiration. This gives the muscles the extra energy they need for muscle contraction — allowing you to 'fight' or to run away.
- Adrenaline also binds to receptors in the liver. This causes the liver to break down its glycogen stores (see. p.238) to release glucose. This increases the blood glucose level, so there's more glucose in the blood to be transported to the cells. This increased glucose can be used to fuel muscle contraction in the 'fight or flight' response.

Thyroxine

Thyroxine is a hormone released by the **thyroid gland**, which is found in the neck. It plays an important role in regulating the basal metabolic rate — the speed at which chemical reactions in the body occur while the body is at rest.

Negative feedback

Your body can control the levels of hormones (and other substances) in the blood. When the levels of certain substances in the body go above or below a normal level, the body triggers responses that help to bring these levels back into a normal range. This is called negative feedback (see Figure 1).

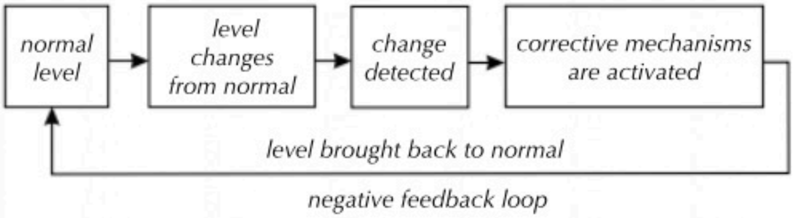

normal level
level changes from normal
change detected
corrective mechanisms are activated
level brought back to normal
negative feedback loop

Figure 1: *A negative feedback mechanism.*

Learning Objectives:

- **H** Be able to explain that adrenaline is produced by the adrenal glands to prepare the body for 'fight or flight', including: increased heart rate, increased blood pressure, increased blood flow to the muscles, and raised blood sugar levels by stimulating the liver to change glycogen into glucose.
- **H** Be able to explain how thyroxine controls metabolic rate as an example of negative feedback, including that:
  - **H** low levels of thyroxine stimulates production of TRH in the hypothalamus, which causes the release of TSH from the pituitary gland;
  - **H** TSH acts on the thyroid to produce thyroxine;
  - **H** when thyroxine levels are normal, thyroxine inhibits the release of TRH and the production of TSH.

Specification References
7.2, 7.3

Tip: **H** You can think about negative feedback working like a thermostat — if the temperature gets too low, the thermostat will turn the heating on, then if the temperature gets too high, it'll turn the heating off again.

Exam Tip H
In the exam you could be asked to interpret graphs like Figure 2. Even if they look different, just apply your understanding of negative feedback to help you work out what the graph is showing you.

A negative feedback system keeps the amount of thyroxine in the blood at the right level (see Figure 2).

Decrease from normal detected

- When the level of thyroxine in the blood is lower than normal, the hypothalamus (a structure in the brain) is stimulated to release thyrotropin releasing hormone (TRH).
- TRH stimulates the pituitary gland to release thyroid stimulating hormone (TSH).
- TSH stimulates the thyroid gland to release thyroxine, so the blood thyroxine level rises back towards normal.

Increase from normal detected

- When the level of thyroxine in the blood is higher than normal, the release of TRH from the hypothalamus is inhibited (stopped).
- This reduces the production of TSH, which reduces the amount of thyroxine released from the thyroid gland. The level of thyroxine in the blood falls back towards normal.

Tip: H A higher than normal thyroxine level also directly inhibits the secretion of TSH from the pituitary gland.

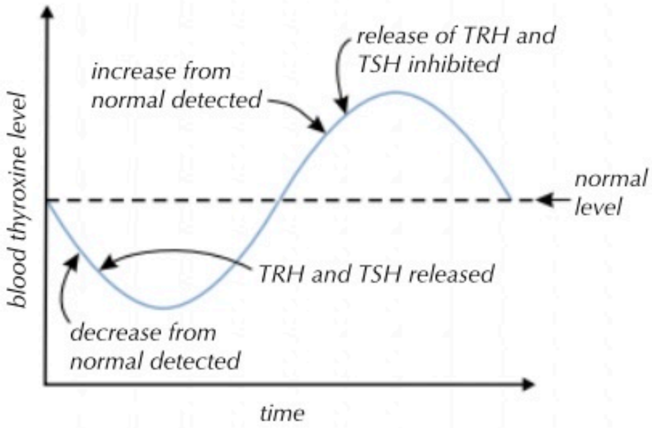


Figure 2: *Graph showing how the level of thyroxine in the blood is controlled by negative feedback.*

Tip: H An underactive thyroid can cause weight gain. Less thyroxine is produced, so your metabolic rate drops. This means that less of the glucose you take in gets broken down in respiration (see page 270), so more is stored as fat.

Practice Questions — Fact Recall

Q1 Name the glands that release adrenaline.

Q2 Give a role of thyroxine in the body.

Practice Question — Application

Q1 Pierre is surprised when a dog jumps up at him.
His heart starts to beat faster.

a) Name the hormone that has caused this response.

b) Explain the purpose of this response.

3. The Menstrual Cycle

Hormones secreted by the ovaries and the pituitary gland are responsible for controlling the changes that occur during a woman's menstrual cycle.

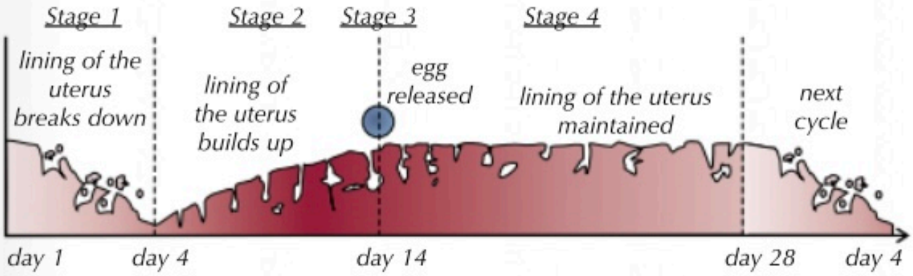
Learning Objectives:

- Be able to describe the stages of the menstrual cycle, including the roles of the hormones oestrogen and progesterone, in the control of the menstrual cycle.
- H Be able to explain the interactions of oestrogen, progesterone, FSH and LH in the repair and maintenance of the uterus wall, ovulation and menstruation.

Specification References
7.4, 7.5

The menstrual cycle

The menstrual cycle is the monthly sequence of events in which the female body releases an egg and prepares the uterus (womb) in case the egg is fertilised. The menstrual cycle has four stages:



Stage 1
Stage 2
Stage 3
Stage 4
lining of the uterus breaks down
lining of the uterus builds up
egg released
lining of the uterus maintained
next cycle
day 1
day 4
day 14
day 28
day 4

Figure 1: *Diagram showing the four stages of the menstrual cycle.*

- **Stage 1**
  Day 1 is when **menstruation** (bleeding) starts. The uterus lining breaks down and is released. This lasts for about four days.
- **Stage 2**
  The lining of the uterus is repaired, from day 4 to day 14, into a thick spongy layer full of blood vessels, ready for a fertilised egg to implant there.
- **Stage 3**
  An egg is released from the ovary at day 14. This is called **ovulation**.
- **Stage 4**
  The lining is then maintained for about 14 days, until day 28. If no fertilised egg has landed on the uterus wall by day 28, the spongy lining starts to break down again and the whole cycle starts again.

Tip: The lining of the uterus is also called the endometrium.

Oestrogen and **progesterone** are hormones with important roles in the menstrual cycle. Oestrogen stimulates the growth of the uterus lining during stage 2 of the menstrual cycle, whereas progesterone is needed to maintain the uterus lining during stage 4.

Hormonal interaction in the menstrual cycle Higher

As well as oestrogen and progesterone, you also need to know about two more important hormones with roles in the menstrual cycle:

- **Follicle-stimulating hormone (FSH)** — causes a **follicle** (an egg and its surrounding cells) to mature in one of the ovaries.
- **Luteinising hormone (LH)** — stimulates the release of an egg at day 14 (ovulation).

Exam Tip H
Make sure you don't talk about egg 'production' or 'development' if you're asked about the menstrual cycle in the exam. Eggs already exist in a woman's ovaries at birth. FSH causes these eggs to mature and LH causes them to be released.

The levels of oestrogen, progesterone, FSH and LH fluctuate throughout the menstrual cycle (see Figure 2). They also interact with each other to promote or inhibit the release of other hormones.

Exam Tip H
In the exam you might be asked to interpret a graph like the one in Figure 2. It might look confusing at first, but if you get your head around what each of the four hormones does, it should start to make more sense. A graph is a really useful way to visualise how the hormones interact when controlling the cycle.

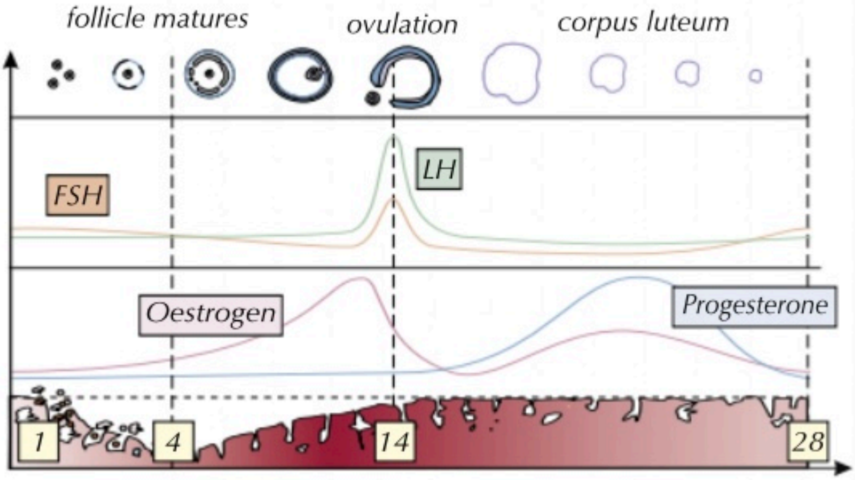


Figure 2: *Diagram showing hormonal changes during the menstrual cycle.*

1. **FSH** is produced in the pituitary gland. It causes a follicle to mature in one of the ovaries. It also stimulates the ovaries to produce oestrogen.

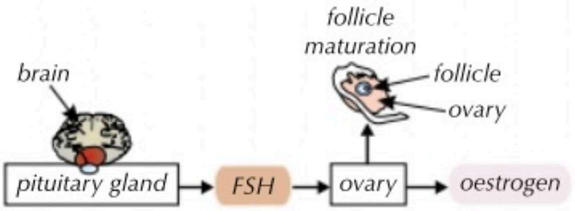


Figure 3: *Diagram showing the role of FSH in the menstrual cycle.*

2. **Oestrogen** is produced in the ovaries and causes the lining of the uterus to thicken and grow. A high level of oestrogen stimulates an LH surge (a rapid increase in LH).

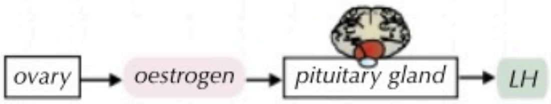


Figure 4: *Diagram showing the role of oestrogen in the menstrual cycle.*

3. **LH** is produced by the pituitary gland. The LH surge causes the follicle to rupture and the egg to be released (ovulation). LH also stimulates the remains of the follicle to develop into a structure called a **corpus luteum**.

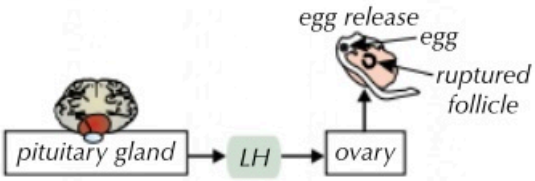


Figure 5: *Diagram showing the role of LH in the menstrual cycle.*

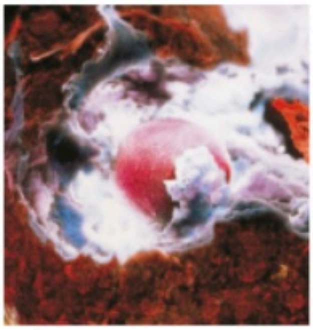


Figure 6: *A microscope image showing an egg (pink oval) being released from an ovary (brown).*

4. **Progesterone** is released by the corpus luteum after ovulation. It maintains the lining of the uterus during the second half of the cycle and inhibits the release of FSH and LH.

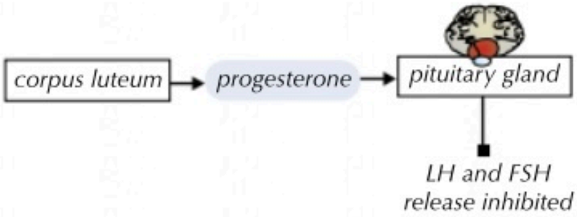


Figure 7: *Diagram showing the role of progesterone in the menstrual cycle.*

When the level of progesterone falls, and there's a low oestrogen level, the uterus lining breaks down. A low progesterone level allows FSH to increase. This allows the whole cycle to start again.

Exam Tip H

A change in the level of one hormone can be used to predict a change in the level of another hormone. E.g. an increase in oestrogen while progesterone levels are low should be followed by an increase in LH.

Pregnancy

If a fertilised egg implants in the uterus (i.e. the woman becomes pregnant) then the level of progesterone will stay high to maintain the lining of the uterus during pregnancy.

Practice Questions — Fact Recall

Q1 Describe what happens during menstruation.

Q2 Name the two hormones involved in the growth and maintenance of the uterus lining.

Q3 What effect does FSH have on follicles in the ovaries?

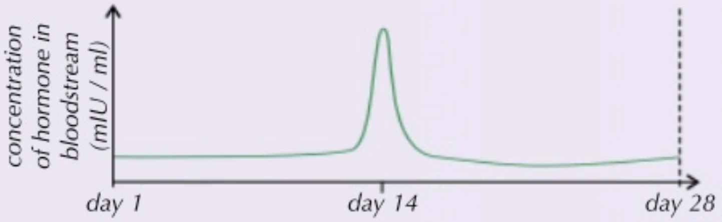
Q4 Give one function of LH.

Q5 Name a hormone that inhibits the release of FSH.

Q6 Which two glands secrete the hormones that control the menstrual cycle?

Practice Question — Application

Q1 The graph below shows the level of a hormone measured in the bloodstream of one woman during her 28 day menstrual cycle.

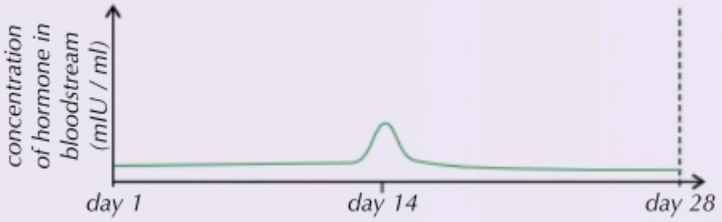


Tip: H Think about what happens around the middle of the menstrual cycle.

a) Which hormone do you think is shown on the graph? Give a reason for your answer.

b) Where is the hormone you gave in part a) produced?

c) The graph below shows the level of the same hormone measured in another woman during her 28 day menstrual cycle. This woman is struggling to have children. Suggest why this might be.



Tip: H Both graphs are drawn to the same scale.

4. Controlling Fertility

Hormones are a key factor in fertility, so they can be used to increase or decrease the chance of becoming pregnant.

Treating infertility Higher

If a person is infertile, it means they can't reproduce naturally. For example, some women have an FSH level that is too low to cause their eggs to mature. This means that no eggs are released and the women can't get pregnant.

There are methods an infertile couple can use to become pregnant, many of which involve hormones. You need to learn these two examples:

Clomifene therapy

Some women are infertile because they don't ovulate or they don't ovulate regularly. These women can take a drug called clomifene. This works by causing more FSH and LH to be released by the body, which stimulate egg maturation and ovulation. By knowing when the woman will be ovulating, the couple can have intercourse during this time period to improve the chance of becoming pregnant.

IVF (*in vitro* fertilisation)

IVF involves collecting eggs from the woman's ovaries and fertilising them in a lab using the man's sperm. The fertilised eggs are then grown into embryos. Once the embryos are tiny balls of cells, one or two of them are transferred to the woman's uterus. (Transferring more than one embryo improves the chance of pregnancy.) FSH and LH are given before egg collection to stimulate egg production (so more than one egg can be collected).

IVF is an example of **Assisted Reproductive Technology** (ART) — fertility treatments that involve eggs being handled (and usually fertilised) outside of the body in a lab.

Hormonal methods of contraception

Contraceptives are used to prevent pregnancy. The hormones oestrogen and progesterone can be taken by women to reduce their **fertility** (their ability to get pregnant) and so are often used as contraceptives.

Oestrogen

Oestrogen can be used to prevent egg release. This may seem kind of strange (since naturally oestrogen helps stimulate the release of eggs — see page 230). But if oestrogen is taken every day to keep the level of it permanently high, it inhibits FSH production, and after a while egg maturation and therefore egg release stop and stay stopped.

Progesterone

Progesterone also reduces fertility. It works in several different ways. For example, it stimulates the production of thick cervical mucus which prevents any sperm getting through the entrance to the uterus (the cervix) and reaching an egg. Some progesterone-only contraceptives can also inhibit egg maturation and therefore the release of an egg too.

Learning Objectives:

- H Be able to explain the use of hormones in Assisted Reproductive Technology (ART) including IVF and clomifene therapy.
- Be able to explain how hormonal contraception influences the menstrual cycle and prevents pregnancy.
- Be able to evaluate hormonal and barrier methods of contraception.

Specification References 7.6 – 7.8

Tip: H Have a look back at pages 229-230 for a reminder of what the hormones FSH and LH do.

Figure 1: *A woman having a hormone injection to prepare for IVF treatment.*

Types of hormonal contraceptive

Hormonal contraceptives can come in different forms:

Tip: An oral contraceptive is taken by mouth.

Examples

- The combined pill is an oral contraceptive. In a 28 day cycle, it is taken once a day for 21 days, followed by a 7 day break. It contains both oestrogen and progesterone.
- The mini-pill is a progesterone-only pill. It is useful for women who can't take contraceptives containing oestrogen (e.g. because of a medical condition). It has to be taken every day.
- The contraceptive patch is a thin, plastic patch that sticks to the skin. Oestrogen and progesterone are released through the skin into the bloodstream. Each patch lasts for 1 week.
- The contraception injection contains progesterone only. Each dose lasts 2 to 3 months.

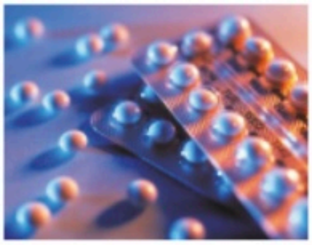


Figure 2: *The combined contraceptive pill.*

Barrier methods of contraception

Barrier forms of contraception are designed to put a barrier between the sperm and egg so they don't meet. Barrier methods are non-hormonal.

- Condoms are worn over the penis during intercourse to prevent the sperm entering the vagina. There are also female condoms that are worn inside the vagina. Condoms are the only form of contraception that will protect against sexually transmitted diseases.
- A diaphragm is a flexible, dome-shaped device that fits over the cervix (the entrance to the uterus) to form a barrier. It is inserted before sex.

Tip: Diaphragms must be used with spermicide — a chemical that disables or kills sperm. Spermicide can be used alone as a contraceptive, but it's not as effective as when used with a diaphragm.

Evaluating methods of contraception

Generally, when used correctly, hormonal methods are more effective at preventing pregnancy than barrier methods. Also, hormonal methods mean that the couple don't have to stop and think about contraception each time they have intercourse (as they would if they relied on barrier methods).

However, hormonal methods can have unpleasant side-effects, such as headaches, acne and mood changes. Barrier methods are generally free from side-effects, although some people can experience allergic reactions to them. Also, hormonal methods don't protect against sexually transmitted infections — condoms are the only form of contraception to do this.

Tip: The method of contraception that is most suitable will differ based on the individual(s) using it.

Exam Tip
In the exam, you could be given data and asked to compare and contrast the effectiveness of different types of contraception. If so, you need to give both the similarities and differences between each type. You won't get all the marks available if you just describe each type individually.

Practice Questions — Fact Recall

Q1 Why is a woman undergoing IVF treatment given FSH and LH before egg collection?

Q2 Explain the function of oestrogen in hormonal contraceptives.

Q3 How do barrier methods of contraception prevent pregnancy?

Topic 7a Checklist — Make sure you know...

Hormones

☐ That hormones are produced in endocrine glands and secreted into the bloodstream where they are carried to target organs.

☐ That the pituitary gland produces many hormones that regulate body conditions, that the pancreas produces insulin, that the adrenal glands produce adrenaline, that the ovaries found in females produce oestrogen and that the testes in males produce testosterone.

Adrenaline and Thyroxine

☐ H That adrenaline produced in the adrenal glands is released to prepare the body for fight or flight.

☐ H That adrenaline increases heart rate and blood pressure so that blood flow to the muscles is increased and the muscle cells receive more oxygen and glucose, allowing for more respiration to occur.

☐ H That adrenaline acts on the liver to stimulate the breakdown of glycogen into glucose to be transported to cells for increased respiration.

☐ H That thyroxine regulates metabolic rate, and that its levels in the blood are controlled by negative feedback.

☐ H That the hypothalamus is stimulated to produce thyrotropin releasing hormone (TRH) when levels of thyroxine are low, and that TRH causes the pituitary gland to release thyroid stimulating hormone (TSH) which stimulates the production of thyroxine in the thyroid.

☐ H That the release of TRH and the production of TSH are inhibited when the levels of thyroxine in the blood are higher than normal.

The Menstrual Cycle

☐ That the menstrual cycle involves the breakdown of the uterus lining during menstruation (bleeding), followed by the repair of the uterus lining, ovulation and maintenance of the uterus lining.

☐ That oestrogen stimulates the growth of the uterus lining and progesterone maintains it.

☐ H That follicle-stimulating hormone (FSH) causes a follicle and its egg to mature in the ovaries and that luteinising hormone (LH) stimulates the release of an egg (ovulation).

☐ H How oestrogen, progesterone, FSH and LH interact during the stages of the menstrual cycle.

Controlling Fertility

☐ H How FSH and LH are used in fertility treatments including clomifene therapy and IVF (an example of Assisted Reproductive Technology).

☐ How different types of hormonal contraception (containing oestrogen and/or progesterone) can be used to prevent pregnancy by influencing the menstrual cycle.

☐ How to evaluate hormonal and barrier methods of contraception, using their advantages and disadvantages.

Exam-style Questions

1 A woman is considering taking a hormonal contraceptive to prevent pregnancy.

(a) (i) Give **one** advantage of using hormonal contraceptives over barrier contraceptives.

(1 mark)

(ii) Suggest **one** reason why the woman may decide to continue to use barrier contraceptives alongside a hormonal contraceptive.

(1 mark)

The woman decides to have the contraceptive injection, where she is injected with progesterone every three months.

(b) Suggest **one** way that the injection will help to prevent her from getting pregnant.

(1 mark)

Another woman and her partner decide to try for a baby.
After unsuccessful attempts at getting pregnant, the woman's doctor explains that she isn't ovulating regularly.

(c) (i) Suggest a drug-based treatment that could increase the chance of pregnancy for this woman.

(1 mark)

(ii) Explain how the treatment you suggested in part **(c)(i)** increases the chance of a woman becoming pregnant.

(3 marks)

(d) Following treatment, the woman becomes pregnant.
During pregnancy the lining of the uterus needs to be maintained.
Name the hormone responsible for maintaining the uterus lining during pregnancy.

(1 mark)

2 Thyroxine is an important hormone of the endocrine system.

(a) In which of the following glands of the endocrine system is thyroxine produced?

A pituitary
B ovary
C thyroid
D pancreas

(1 mark)

(b) Describe how the body responds to low levels of thyroxine in the blood.

(3 marks)

One role of thyroxine is the regulation of the basal metabolic rate.
Basal metabolic rate can be given as the number of calories burned at rest in a certain time.

(c) A man's basal metabolic rate is 1860 kcal/day.
Calculate how many calories the man burns at rest during six hours.

(2 marks)

1. Homeostasis

The internal conditions in the body must be kept constant — this stops cell damage that could happen if we didn't keep on top of things. Luckily there are some clever systems in place to keep everything plodding along steadily.

Learning Objective:

- Be able to explain the importance of maintaining a constant internal environment in response to internal and external change.

Specification Reference 7.9

What is homeostasis?

The conditions inside your body need to be kept steady, even when the external environment changes. This is really important because your cells need the right conditions in order to function properly, including the right conditions for enzyme action (see pages 37-38). Homeostasis is the way in which everything is kept at the right level.

Homeostasis is the regulation of the conditions inside your body (and cells) to maintain a constant internal environment, in response to changes in both internal and external conditions.

Tip: It can be dangerous for your health if conditions in the body vary too much from normal levels.

Examples of homeostasis in action include:

Examples

- Osmoregulation (regulating water content) — you need to keep a balance between the water you gain (in drink, food, and from respiration) and water you urinate, sweat and breathe out.
- Thermoregulation (regulating body temperature) — you need to reduce your body temperature when you're hot, but increase it when the environment is cold.
- Blood glucose regulation — you need to make sure the amount of glucose in your blood doesn't get too high or too low (see p.238-239).

Tip: There's more on osmoregulation on pages 246-248. There's more on thermoregulation on pages 243-245.

Negative feedback

Negative feedback systems (see p.227) help to keep conditions in your body steady. This means that if a condition changes away from the normal level, a response is triggered that counteracts the change. E.g. a rise in blood glucose level causes a response that lowers blood glucose level (and vice versa).

Tip: A negative feedback system responds when a level changes from normal, in order to bring the level back to normal. It's a continuous, looping process.

Practice Questions — Fact Recall

Q1 Define homeostasis.

Q2 Give two examples of conditions in your internal environment that need regulating and maintaining.

Learning Objectives:

- Be able to explain how the hormone insulin controls blood glucose concentration.
- **H** Be able to explain how blood glucose concentration is regulated by glucagon.
- Be able to explain the cause of type 1 diabetes and how it is controlled.
- Be able to explain the cause of type 2 diabetes and how it is controlled.
- Be able to evaluate the correlation between body mass and type 2 diabetes including waist:hip calculations and BMI, using the BMI equation:

$$\text{BMI} = \frac{\text{mass (kg)}}{(\text{height (m)})^2}.$$

Specification References
7.13 – 7.17

2. Controlling Blood Glucose

Your blood glucose level needs to be carefully regulated. This is done with the help of hormones produced by the pancreas. However, if things don't work quite as they should, it can result in a condition called diabetes...

Glucose concentration of the blood

Glucose is a type of sugar. Throughout the day the blood glucose level varies:

Examples

- Eating foods containing carbohydrate puts glucose into the blood from the small intestine.
- The normal metabolism of cells removes glucose from the blood.
- Vigorous exercise removes much more glucose from the blood.

Excess glucose is stored as **glycogen** in the liver and in the muscles. When these stores are full, the excess glucose is stored as lipid (fat) in the tissues.

Hormonal control of blood glucose

The level of glucose in the blood must be kept steady. Changes in the blood glucose level are monitored by the **pancreas**. The pancreas produces hormones which help to control the blood glucose level.

Insulin

Insulin is a hormone produced by the pancreas. It decreases the blood glucose level when it gets too high. Here's what happens:

1. After a meal containing carbohydrate, a person's blood glucose level rises. This rise is detected by the pancreas.
2. The pancreas responds by producing insulin, which is secreted into the blood.
3. Insulin causes body cells to take up more glucose from the blood. Cells in the liver and muscles can take up glucose and convert it into the storage molecule glycogen.
4. This causes the blood glucose level to fall.

This process is shown in Figure 1.

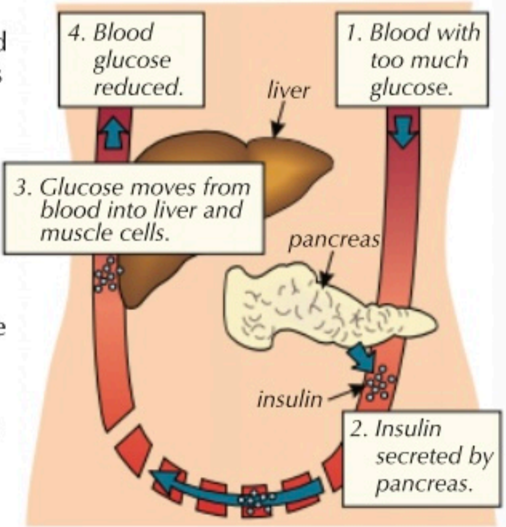

4. Blood glucose reduced.
liver
1. Blood with too much glucose.
3. Glucose moves from blood into liver and muscle cells.
pancreas
insulin
2. Insulin secreted by pancreas.

Figure 1: *Diagram showing the role of insulin in the control of blood glucose.*

Glucagon Higher

Glucagon is another hormone produced by the pancreas. It increases the blood glucose level when it gets too low. Here's what happens:

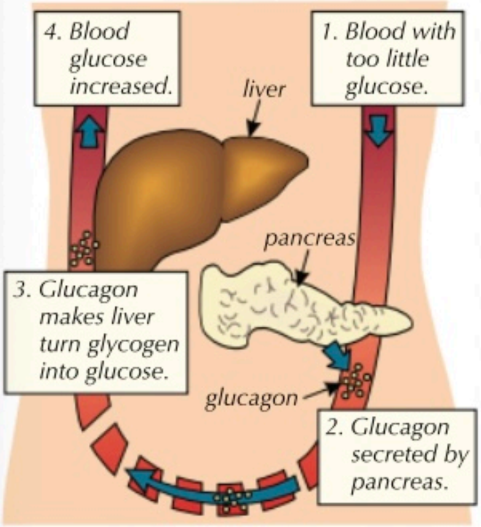

4. Blood glucose increased.
1. Blood with too little glucose.
liver
pancreas
3. Glucagon makes liver turn glycogen into glucose.
glucagon
2. Glucagon secreted by pancreas.

Figure 2: *Diagram showing the role of glucagon in the control of blood glucose.*

1. If a person's blood glucose level decreases, the fall is detected by the pancreas.
2. The pancreas responds by producing glucagon, which is secreted into the blood.
3. Glucagon causes the glycogen stored in the liver and muscles to be converted back into glucose, which enters the blood.
4. This causes the blood glucose level to rise.

This process is shown in Figure 2.

Exam Tip H
The words 'glucagon' and 'glycogen' look and sound very similar. You need to make sure you get the spelling of these words spot on in the exam. E.g. if you write 'glycogon' the examiner won't know whether you mean glucagon or glycogen so you won't get the marks.

Tip: H Glucagon works with insulin to control blood glucose level in a negative feedback cycle — together they keep blood glucose around its optimum. (See page 227 for more on negative feedback.)

Type 1 diabetes

Type 1 diabetes is a condition where the pancreas produces very little or no insulin. The result is that a person's blood glucose can rise to a level that can kill them.

Controlling type 1 diabetes

Type 1 diabetes needs to be controlled with **insulin therapy.**

This usually involves injecting insulin into subcutaneous tissue (fatty tissue just under the skin). From there it will enter the bloodstream. People with type 1 diabetes usually have several injections of insulin throughout the day, which are likely to be around mealtimes.

Insulin injections make sure glucose is removed from the blood quickly once the food has been digested. This stops the level of glucose in the blood from getting too high and is a very effective treatment.

The amount of insulin that needs to be injected depends on the person's diet and how active they are, since these things will affect their blood glucose level. Injecting too much insulin could lead to a dangerously low blood glucose level.

Tip: Remember, insulin reduces blood glucose level.

Figure 3: *A person injecting insulin.*

Tip: Insulin can't be taken in a pill or tablet — the enzymes in the stomach completely destroy it before it reaches the bloodstream. That's why it's normally injected.

Tip: Prolonged periods of high blood glucose levels can cause damage to organs such as the eyes, heart and kidneys, resulting in long-term health problems.

Type 2 diabetes

Type 2 diabetes is a condition where the pancreas doesn't produce enough insulin, or when a person becomes resistant to their own insulin (their body's cells don't respond properly to the hormone). This can also cause a person's blood glucose level to rise to a dangerous level.

Being overweight can increase your chance of developing type 2 diabetes, as obesity is a major risk factor in the development of the disease (see below).

Controlling type 2 diabetes

Type 2 diabetes can be controlled by eating a healthy diet, getting regular exercise and losing weight if needed. These things can all help to lower the blood glucose level. Some people with type 2 diabetes also need to have medication or insulin injections to control their blood glucose level.

Tip: There are different medications available for type 2 diabetes. Some can make body cells more sensitive to insulin.

Correlation between type 2 diabetes and obesity

There is a correlation (see p.18) between type 2 diabetes and obesity — this means that obese people have an increased risk of developing type 2 diabetes. People can be classified as obese by looking at their body mass index (see p.190 for more). Body mass index (BMI) is calculated using this formula:

$$\text{BMI} = \frac{\text{mass (kg)}}{\left(\text{height (m)}\right)^2}$$

Exam Tip
In the exam you might be asked to compare type 1 and type 2 diabetes. It might help to draw a table comparing the two. You could include what they are and how they can be controlled.

Where the body stores excess fat is also important — storing a lot of fat around the abdomen (tummy area) is associated with an increased risk of developing type 2 diabetes. Calculating a person's waist-to-hip ratio gives an indication of how fat is stored. This is the formula you need:

$$\text{waist-to-hip ratio} = \frac{\text{waist circumference (cm)}}{\text{hip circumference (cm)}}$$

Tip: See pages 190-191 for more on calculating BMI and waist-to-hip ratios.

A ratio above 1.0 for men and above 0.85 for women is associated with an increased risk of type 2 diabetes because it indicates that a lot of fat is being stored around the abdomen.

Interpreting blood glucose level graphs

The changes in a person's blood glucose level over time can be shown by a graph. The shape of the graph can vary, depending on whether the person has diabetes — see Figure 4 on the next page. You might need to explain what graphs like this are showing in the exam.

Example

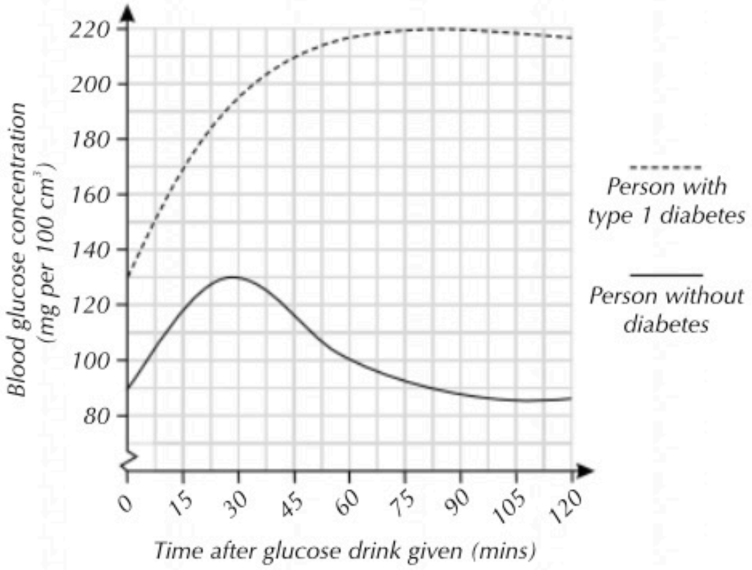


Figure 4: *Graph showing the change in blood glucose concentration over time after consuming a glucose drink for a person with type 1 diabetes and a person without diabetes.*

Here's what Figure 4 is showing:

Person without diabetes

In the initial 30 minutes after consuming the glucose drink, their blood glucose concentration rises from 90 mg/100 cm^3 to 130 mg/100 cm^3. After 30 minutes, their blood glucose concentration begins to fall. This is because as the glucose level rises above normal, the pancreas responds by releasing insulin into the blood. The insulin causes body cells to take up the glucose.

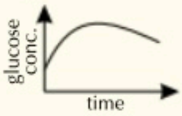
After about 80 minutes, the blood glucose concentration is back to its normal level of 90 mg/100 cm^3, so the pancreas stops releasing insulin. However, the blood glucose concentration then falls slightly below normal — this is due to some insulin still remaining in the blood.

Person with type 1 diabetes

After the person with type 1 diabetes consumes the glucose drink, their blood glucose concentration rises higher than that of the person without diabetes, from 130 mg/100 cm^3 to 220 mg/100 cm^3. Their glucose level then remains high.

This is because their pancreas produces very little or no insulin in response to the rising amount of glucose in the blood, so they are not able to control their blood glucose level.

Tip: If the blood glucose concentration rises high then decreases slowly, the person may be resistant to insulin — this is type 2 diabetes. E.g.



Their pancreas is producing insulin but it's not having the proper effect on the body cells.

Tip: There is a time delay between the release of insulin and the reduction of blood glucose concentration. This is because the insulin first needs to travel in the blood to its target cells.

Tip: **H** As the glucose level falls below normal, the pancreas responds by releasing glucagon into the blood. Glucagon works to bring the blood glucose back up to its normal level.

Practice Questions — Fact Recall

Q1 Where in the body is the hormone insulin produced?

Q2 What effect does insulin have on the body's cells?

Q3 Where in the body is the hormone glucagon produced?

Q4 How does glucagon increase blood glucose levels?

Q5 What is type 1 diabetes?

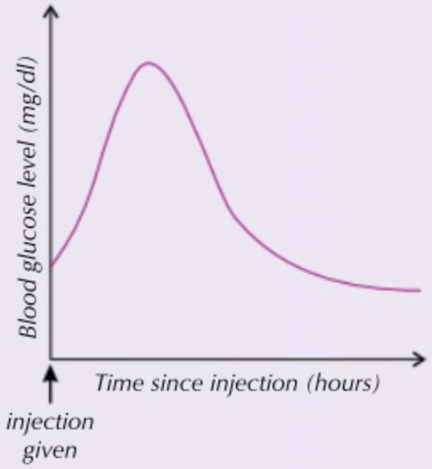
Q6 Give two ways type 2 diabetes can be controlled.

Exam Tip

If you are given a graph on blood glucose level in the exam, it's a good idea to look at it carefully and try to work out what it is showing before you start answering the questions. It sounds obvious, but if you just jump straight in you might miss something important.

Practice Question — Application

Q1 In a study, a hormone was injected into a subject while their blood glucose level was monitored. The results are shown in the graph.



a) What hormone do you think was injected? Explain your answer.

b) i) Name the other main hormone that affects the blood glucose level.

ii) What do you think would happen to the blood glucose level if this hormone had been injected instead? Explain your answer.

3. Thermoregulation

Ever wondered why you get all sweaty when you're too hot, and shivery when you're too cold? It's just your body acting to control your temperature...

Monitoring body temperature

Body temperature needs to be kept at around 37 °C because this is the temperature at which enzymes in the human body work best. Below this temperature enzyme activity slows down, and above this temperature enzymes may start to denature so they can't work at all.

Body temperature must be carefully monitored and controlled — homeostasis constantly balances the amount of energy gained (e.g. through respiration) and lost to keep the core body temperature at 37 °C.

This is where the **thermoregulatory centre** comes in. It is located in the **hypothalamus** (a structure in the brain) and acts as your own personal thermostat. To do this, it receives information about body temperature from receptors — groups of cells which are sensitive to stimuli (see page 69). These include:

1. Receptors in the thermoregulatory centre that are sensitive to the temperature of the blood flowing through the brain.
2. Receptors in the skin that send information about skin temperature via nervous impulses. These receptors are located in the **epidermis** (the outer layer of the skin) and in the **dermis** (a deeper layer of skin just below the epidermis).

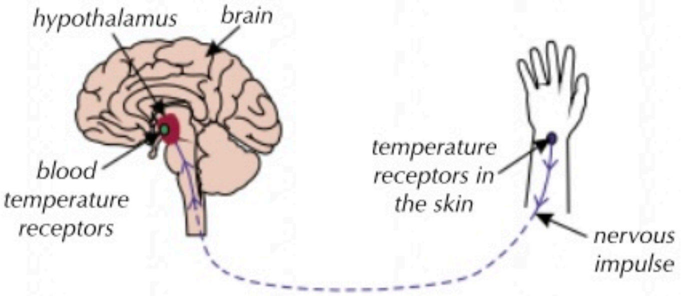

hypothalamus
brain
blood temperature receptors
temperature receptors in the skin
nervous impulse

Figure 1: *Diagram showing how the hypothalamus monitors temperature.*

How is body temperature controlled?

The temperature of the body is kept around a constant level due to a **negative feedback system** (see page 227) — if it gets too high or too low, the body responds to bring the temperature back to optimum.

Responding to a rise in body temperature

When the temperature receptors detect that core body temperature is too high, they send impulses to the hypothalamus, which coordinates the response. The hypothalamus processes the information from the temperature receptors and triggers the effectors automatically — see Figure 2 on the next page. The effectors produce a response that increases the amount of heat lost from the body and the body cools down.

Learning Objectives:
- Be able to explain the importance of homeostasis, including the effect of thermoregulation on enzyme activity.
- Be able to explain how thermoregulation takes place, with reference to the function of the skin, including the roles of the hypothalamus, dermis and epidermis.
- **H** Be able to explain how thermoregulation takes place, with reference to vasoconstriction and vasodilation.
- Be able to explain how thermoregulation takes place, with reference to shivering.

Specification References
7.10B – 7.12B

Tip: See page 37 for more on how temperature affects enzyme activity.

Tip: Core body temperature refers to the temperature deep inside the body, where your internal organs are, rather than the temperature at the skin or in the limbs.

Tip: Mammals and birds are able to regulate their own body temperature using a negative feedback system, but not all organisms can (e.g. fish and reptiles).

Tip: Effectors are muscles or glands which respond to nervous impulses and bring about a response to a stimulus. See page 69 for more.

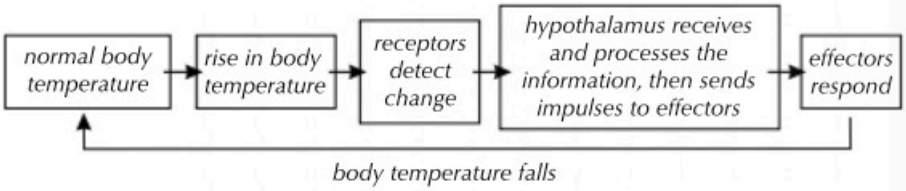

normal body temperature
rise in body temperature
receptors detect change
hypothalamus receives and processes the information, then sends impulses to effectors
effectors respond
body temperature falls

Figure 2: *Negative feedback mechanism activated by a rise in body temperature.*

Responses that reduce core body temperature

When your core body temperature gets too high, your body responds in the following ways:

1. Erector muscles in the dermis relax, which makes hairs on the skin lie flat. This means less air is trapped near the surface of the skin, so there isn't a layer of insulating air surrounding the skin. This allows heat to be transferred to the environment more easily.
2. Sweat is produced by sweat glands in the dermis, and released onto the surface of the skin through pores in the epidermis. When the sweat evaporates from the skin, it transfers energy to the environment, reducing body temperature.
3. H The blood vessels supplying the skin capillaries dilate (get wider) so more blood flows close to the surface of the skin. This is called **vasodilation**. It helps transfer energy from the skin to the environment.

Figure 3: *Exercise can increase core body temperature, which makes you sweat and increases blood flow to the skin.*

Tip: Sweat is made up of salts dissolved in water.

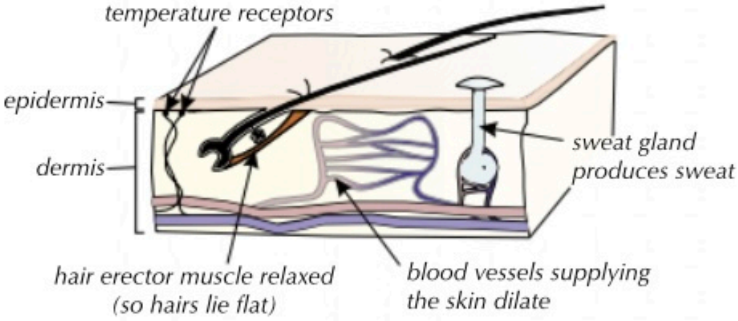

temperature receptors
epidermis
dermis
sweat gland produces sweat
hair erector muscle relaxed (so hairs lie flat)
blood vessels supplying the skin dilate

Figure 4: *Some of the body's responses to a high core body temperature.*

Responding to a fall in body temperature

When the temperature receptors detect that core body temperature is too low, they send impulses to the hypothalamus, which processes the information and triggers the effectors to reduce the amount of heat lost from the body (see next page).

The effectors, e.g. muscles, produce a response that counteracts the change and the body warms up — see Figure 5.

Tip: Some effectors work antagonistically, e.g. one effector heats and another cools — they'll work at the same time to achieve a very precise temperature. This mechanism allows a more sensitive response.

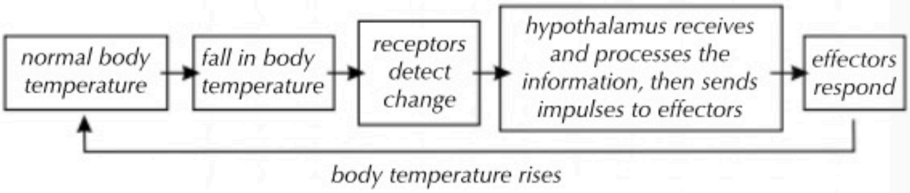

normal body temperature
fall in body temperature
receptors detect change
hypothalamus receives and processes the information, then sends impulses to effectors
effectors respond
body temperature rises

Figure 5: *Negative feedback mechanism activated by a fall in body temperature.*

Responses that increase core body temperature

When your core body temperature drops too low, your body responds in the following ways:

1. Erector muscles in the dermis contract, which makes hairs on the skin stand up. This traps an insulating layer of air next to the skin, reducing the amount of energy transferred to the environment.
2. Very little sweat is produced.
3. H Blood vessels supplying skin capillaries constrict (get narrower) to reduce the skin's blood supply. This is called **vasoconstriction**. It reduces the amount of blood that flows close to the surface of the skin and so less energy is transferred from the skin to the environment.
4. When you're cold you **shiver** (your muscles contract automatically). This increases your rate of respiration, which transfers more energy to warm the body.

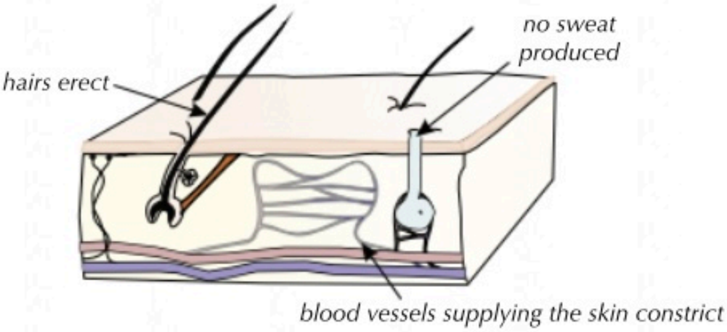


Figure 7: *Some of the body's responses to a low core body temperature.*

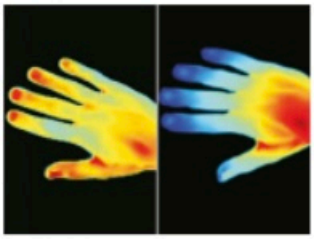


Figure 6: *A thermogram showing a hand before (left) and after (right) vasoconstriction in the fingers. The colours show the variation in temperature in different parts of the hand — red is warmest, blue is coldest. After constriction of the blood vessels, the fingers are much cooler.*

Tip: Respiration transfers energy from glucose — see p.270.

Practice Questions — Fact Recall

Q1 The thermoregulatory centre in the hypothalamus regulates body temperature. Where does it receive inputs about body temperature from?

Q2 a) What happens to the blood vessels supplying the skin capillaries when you get too hot?

b) Explain how the response you gave in part a) helps to reduce body temperature.

Q3 Describe the pathway of the response from receptors to effectors when core body temperature falls.

Practice Question — Application

Q1 Gena is out walking and has forgotten her coat. The weather has changed and the temperature has begun to fall.

a) Describe two ways in which Gena's body will respond in order to help her try to maintain her body temperature.

b) Explain how the responses you gave in part a) help Gena to maintain her body temperature.

Tip: In order to work out how the body will respond to a change in temperature, you first need to work out how the situation is affecting the body temperature — has the body temperature dropped or risen?

4. Osmoregulation and The Kidneys

The water level in cells is very important — organisms need to maintain the concentration of their cell contents at the correct level for cell activity. The kidneys are really important in osmoregulation (regulating water content).

Learning Objectives:

- Be able to explain the importance of homeostasis, including the effect of osmoregulation on animal cells.
- Be able to describe the structure of the urinary system.
- Know that urea is produced from the breakdown of excess amino acids in the liver.
- Be able to explain how the structure of the nephron is related to its function in filtering the blood and forming urine, including filtration in the glomerulus and Bowman's capsule, selective reabsorption of glucose and reabsorption of water.
- H Be able to explain the effect of ADH on the permeability of the collecting duct in regulating the water content of the blood.

Specification References 7.10B, 7.18B – 7.20B, 7.22B

The importance of osmoregulation

The water content of the blood must be controlled in order to keep cells functioning normally. If the concentration of water in the blood is too high, then water will move into the body cells by osmosis (see p.49-50). If too much water moves into the cells, they may burst. (Unlike plant cells, animal cells don't have a rigid cell wall to help prevent them from bursting.)

If the concentration of water in the blood is too low, then water will move out of the cells and into the blood by osmosis. This causes the cells to shrink (see Figure 1).

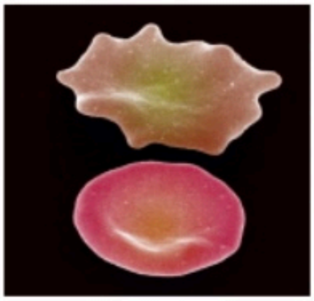


Figure 1: *A healthy red blood cell (bottom) and a red blood cell that has shrunk due to loss of water by osmosis (top).*

The **kidneys** help to regulate water content by controlling how much water is reabsorbed and how much water is lost in urine.

The role of the kidneys

The kidneys are part of the urinary system (which you need to be able to describe the structure of for your exam — see Figure 2). The kidneys make urine by taking waste products (and other unwanted substances) out of your blood. The substances that are removed from the body in urine include **urea** (a waste product produced in the liver from the breakdown of excess amino acids), excess ions and water.

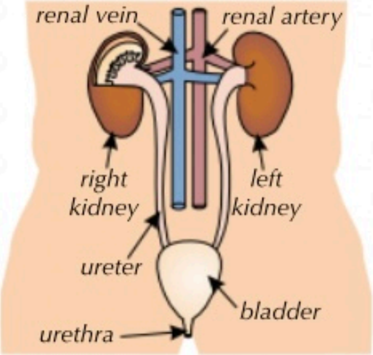


Figure 2: *Diagram showing the location of the kidneys and associated structures.*

Substances are filtered out of the blood as it passes through the kidneys. This process is called **ultrafiltration**. Useful substances, including all the glucose, some ions and the right amount of water, are then absorbed back into the blood. This process is called **selective reabsorption**. There's more about both of these processes over the next two pages. The urine is then excreted (removed from the body — see page 248).

The nephrons

Nephrons are structures found in the kidneys (see Figure 3). Ultrafiltration and selective reabsorption both take place in the nephrons.

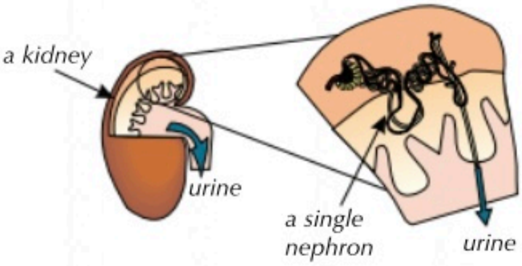

a kidney
urine
a single nephron
urine

Figure 3: *Diagram showing a single nephron within a kidney.*

Tip: The long, winding tubes in the nephron provide a large surface area for the selective reabsorption of nutrients to the blood.

Ultrafiltration

At the start of the nephron, blood from the renal artery flows through a network of capillaries called the glomerulus. The **glomerulus** is surrounded by a sac of tissue known as the **Bowman's capsule** (see Figure 4).

The liquid part of the blood (containing water, urea, ions and glucose) is forced out of the glomerulus and into the Bowman's capsule at high pressure. This process is known as ultrafiltration. Bigger molecules (e.g. proteins) and blood cells can't pass through the membranes between the glomerulus and Bowman's capsule, so remain in the blood.

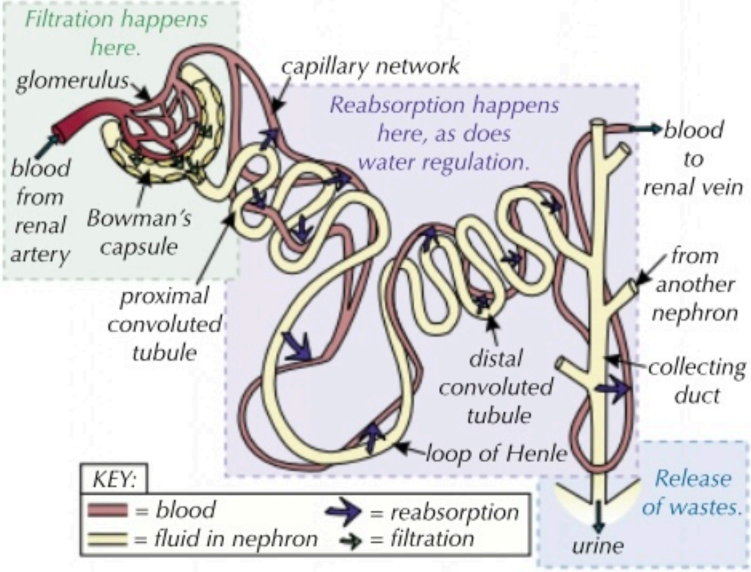

Filtration happens here.
glomerulus
capillary network
Reabsorption happens here, as does water regulation.
blood to renal vein
blood from renal artery
Bowman's capsule
proximal convoluted tubule
from another nephron
distal convoluted tubule
collecting duct
loop of Henle
Release of wastes.
KEY:
= blood
= fluid in nephron
= reabsorption
= filtration
urine

Figure 4: *Diagram showing an enlarged view of a single nephron.*

Selective reabsorption

After the filtered liquid leaves the Bowman's capsule, it passes through the proximal convoluted tubule, the loop of Henle and the distal convoluted tubule. As the liquid flows along these parts of the nephron, useful substances are **selectively reabsorbed** into the blood.

Tip: Animals living in drought conditions have longer loops of Henle to reabsorb more water.

Tip: Selective reabsorption uses active transport.

All the glucose in the liquid is selectively reabsorbed — it's moved back into the blood against the concentration gradient. A sufficient amount of ions are reabsorbed, along with a sufficient amount of water.

Excretion

Whatever isn't reabsorbed from the nephron into the blood (e.g. urea, excess water, excess ions) continues out of the nephron via the **collecting duct**. It then passes into the ureter and down to the bladder as urine. Urine is released from the bladder through the urethra.

Anti-diuretic hormone (ADH) Higher

Tip: H We lose water from our skin in sweat and from our lungs when we breathe out. We can't control how much water we lose in these ways, so the amount of water in our bodies is balanced by the amount we consume (in food and drink) and the amount removed by our kidneys in urine.

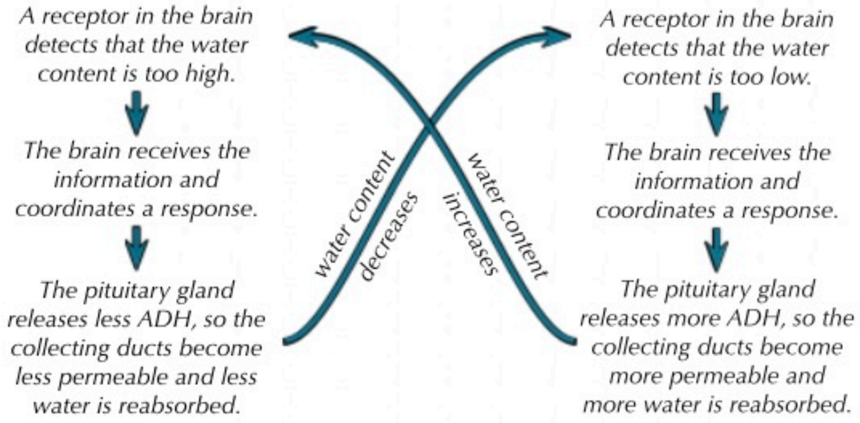
The kidneys can let more or less water move out of the nephrons to change the water content of the blood — the more water that leaves the nephrons and is reabsorbed into the blood, the more concentrated the urine will be. A smaller volume of urine will also be produced.

This process is controlled by a hormone called anti-diuretic hormone (ADH). ADH makes the collecting ducts of the nephrons more permeable to water, so that more water is reabsorbed into the blood. This stops the body from becoming dehydrated.

ADH is released into the bloodstream by the pituitary gland (see page 224). The brain monitors the water content of the blood and instructs the pituitary gland to release ADH into the blood according to how much is needed.

Tip: H For more information on negative feedback go to p.227.

The whole process of water content regulation is controlled by negative feedback. This means that if the water content gets too high or too low a mechanism will be triggered that brings it back to normal (see Figure 5).



A receptor in the brain detects that the water content is too high.
↓
The brain receives the information and coordinates a response.
↓
The pituitary gland releases less ADH, so the collecting ducts become less permeable and less water is reabsorbed.

A receptor in the brain detects that the water content is too low.
↓
The brain receives the information and coordinates a response.
↓
The pituitary gland releases more ADH, so the collecting ducts become more permeable and more water is reabsorbed.

Figure 5: *How ADH secretion is controlled by negative feedback.*

Example **Higher**

If the amount of sodium ions in the blood increases, the concentration of water in the blood will fall. The brain will detect that the blood needs more water, so it will instruct the pituitary gland to release more ADH. More water will be reabsorbed from the collecting ducts so the water content of the blood will rise.

Practice Questions — Fact Recall

Q1 What is osmoregulation and why is it important?

Q2 Urea is excreted in urine. How is urea produced?

Q3 What is the name of the process in the kidneys where useful substances are absorbed back into the blood?

Q4 Name two substances that are absorbed back into the blood in the kidney.

Q5 Describe what happens during ultrafiltration in the kidneys.

Q6 Explain how ADH helps to increase the water content of the blood if it gets too low.

Practice Questions — Application

Q1 A red blood cell is placed a solution of pure water. Suggest and explain what will happen to the cell.

Q2 This table shows the average rate of filtration and reabsorption of various substances found in the blood, in a person with healthy kidneys.

Substance	Filtration rate	Reabsorption rate
Water	180 litres per day	178.2 litres per day
Glucose	800 millimoles per day	800 millimoles per day
Potassium ions	720 millimoles per day	500 millimoles per day

a) i) What percentage of the filtered water is reabsorbed?

ii) What do you think would happen to this percentage if the person went for a run on a hot day and didn't consume any extra liquid? Explain your answer.

iii) What effect do you think this would have on the urine produced by the person?

b) Calculate the average amount of potassium ions found in the urine of this person per day.

Exam Tip

In the exam you could be given some figures to do with the kidneys and asked to do some calculations using them. Just make sure you read the information carefully, so that you're using the correct figures. And the good news is that you can take a calculator into the exam with you. Hooray.

5. Kidney Failure

As you've seen, the kidneys are a really important pair of organs. If they stop working properly it can cause big problems in the body...

Learning Objective:

- Be able to describe the treatments for kidney failure, including kidney dialysis and organ donation.

Specification Reference 7.21B

The effects of kidney failure

The kidneys play a number of important roles in the body (see page 246). If the kidneys don't work properly, waste substances build up in the blood and you lose your ability to control the levels of ions and water in your body. This can cause problems in the heart, bones, nervous system, stomach, mouth, etc. If left untreated, kidney failure will eventually result in death.

Fortunately there are treatment options available. People with kidney failure can be kept alive by:

1. Having **dialysis** treatment — where machines do the job of the kidneys.
2. Having a **kidney transplant** — where the diseased kidney is replaced by a healthy one.

Kidney dialysis

Tip: Dialysis is usually carried out 3 times a week, with each session lasting 3-4 hours.

Dialysis machines take over the role of failing kidneys and filter the blood. Dialysis has to be done regularly to keep the concentrations of dissolved substances (e.g. glucose, ions, etc.) in the blood at normal levels, and to remove waste substances.

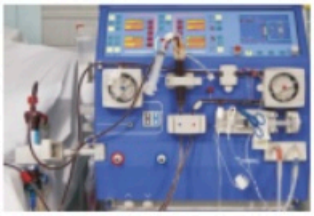


Figure 1: *A dialysis machine.*

How does a dialysis machine work?

In a dialysis machine the person's blood flows alongside a partially permeable membrane, surrounded by **dialysis fluid** (see Figure 2).

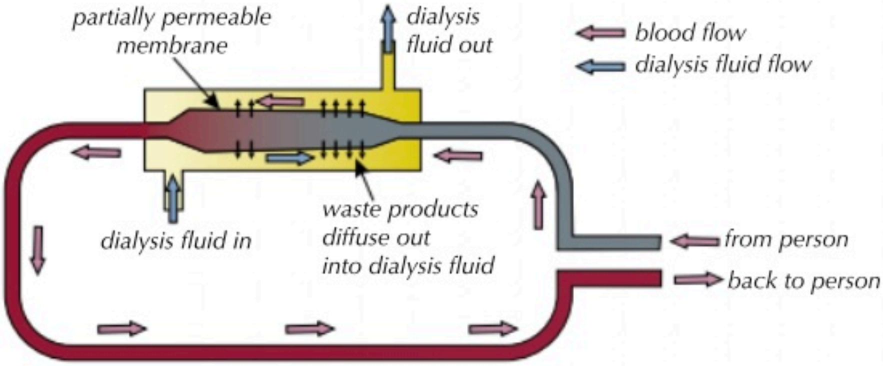


Figure 2: *Diagram showing how a dialysis machine works.*

Tip: Substances diffuse from an area of higher concentration to an area of lower concentration. This means that if there's a higher concentration of a substance in the blood, it will diffuse across the partially permeable membrane into the dialysis fluid.

The partially permeable membrane allows things like ions and waste substances through, but not big molecules like proteins (just like the membranes in the kidney). The dialysis fluid has the same concentration of dissolved ions and glucose as healthy blood. This means that useful dissolved ions and glucose won't be lost from the blood during dialysis. Only waste substances (e.g. urea) and excess ions and water diffuse across the membrane.

Kidney transplants

At the moment, the only cure for kidney disease is to have a kidney transplant. Healthy kidneys are usually transplanted from people who have died suddenly, say in a car accident, and who are on the organ donor register (provided their relatives agree too). Kidneys can also be transplanted from people who are still alive (as we all have two kidneys, but can survive with just one) but there is a small risk to the person donating the kidney.

NHS Organ Donor Register
donorcard

Figure 3: *An NHS donor card. People on the organ donor register carry this card to let medical staff know that they wish to donate their organs after they have died.*

Rejection

A problem of kidney transplants is that the donor kidney can be rejected by the recipient's immune system — this happens when **antigens** on the donor kidney aren't recognised as being part of the body by the recipient's white blood cells. The white blood cells produce **antibodies** to attack the donor cells as a result (see Figure 4).

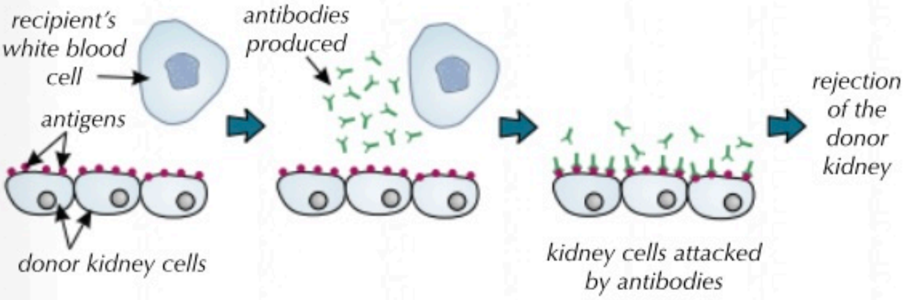

recipient's white blood cell
antigens
donor kidney cells
antibodies produced
kidney cells attacked by antibodies
rejection of the donor kidney

Figure 4: *Diagram showing the possible reaction of a recipient's immune system in response to a donor kidney.*

Tip: The recipient is the person who receives the kidney.

Tip: Antigens are unique molecules found on a cell's surface. Antibodies are produced by white blood cells in response to the presence of a foreign antigen — see page 165.

Preventing rejection

To help prevent rejection of the donor organ, precautions are taken:

- A donor with a tissue-type that closely matches the patient's is chosen. Tissue-type is based on a cell's antigens. The more similar the tissue-types of the donor and the patient, the more similar the antigens. This reduces the chance of the patient's white blood cells identifying the donor antigens as 'foreign' and producing antibodies to attack the donor organ.
- The recipient is treated with drugs that suppress the immune system. These drugs reduce the production of antibodies by the white blood cells, so that the immune system won't attack the transplanted kidney.

Tip: Donor kidneys are ideally matched by blood type (and a few other things) to the recipient, which make them less likely to be rejected. However, it means a potentially long waiting time for a suitable kidney.

Practice Questions — Fact Recall

Q1 True or False? People with kidney failure only need dialysis once.

Q2 How does a kidney transplant cure kidney disease?

Tip: A dialysis machine is like an artificial kidney. If you're struggling with Q1, think about the role of a healthy kidney in the body — it regulates the water and ion content of the blood and removes waste products.

Practice Question — Application

Q1 The level of dissolved sodium found in dialysis fluid before a dialysis session is similar to the typical level of dissolved sodium found in the blood plasma.

a) Why is the level of dissolved sodium in the dialysis fluid similar to the level in the blood plasma?

Blood plasma contains urea. Dialysis fluid does not.

b) i) Why does the blood plasma contain urea?

ii) Explain why it's important that the dialysis fluid doesn't contain urea.

Blood plasma also contains glucose.

c) Suggest how the amount of glucose in the dialysis fluid would compare to the amount of glucose in the blood plasma. Explain your answer.

Topic 7b Checklist — Make sure you know...

Homeostasis

- ☐ That homeostasis is the regulation of the conditions inside your body (and cells) to maintain a constant internal environment in response to changes in both internal and external conditions.
- ☐ That the conditions in the body need to be kept steady in order for body cells to function properly.

Controlling Blood Glucose

- ☐ That insulin is a hormone secreted by the pancreas to reduce the blood glucose level and that it works by causing cells in the liver and muscles to take up more glucose from the blood and convert it into glycogen for storage.
- ☐ **H** That glucagon is a hormone secreted by the pancreas to increase the blood glucose level and that it works by causing glycogen in the liver and muscles to be converted back into glucose.
- ☐ That type 1 diabetes is caused by the pancreas producing very little or no insulin, and can be controlled through insulin therapy.
- ☐ That type 2 diabetes is caused by the pancreas failing to produce enough insulin, or when a person becomes resistant to their own insulin, and can be controlled by eating a healthy diet, exercising regularly, losing weight if needed and sometimes by receiving medication or insulin injections.
- ☐ That there is a correlation between obesity and type 2 diabetes and that obese people have an increased risk of developing type 2 diabetes.
- ☐ How to calculate BMI and waist-to-hip ratios to determine whether or not a person is obese.

cont...

Thermoregulation

☐ That homeostasis controls the temperature of the body so that enzymes work properly.

☐ That the thermoregulatory centre in the hypothalamus monitors and controls body temperature.

☐ That the hypothalamus receives information about blood temperature from receptors in the brain, and information about skin temperature from receptors in the dermis and epidermis.

☐ How the skin responds when body temperature is too high — erector muscles in the dermis relax to make hairs lie flat and sweat glands increase sweat production.

☐ How the skin responds when body temperature is too low — erector muscles in the dermis contract to make hairs stand on end and sweat glands reduce sweat production.

☐ **H** How the temperature of the body is controlled by vasodilation (widening of the blood vessels supplying the skin) and vasoconstriction (constriction of the blood vessels supplying the skin).

☐ That shivering warms the body by increasing the rate of respiration of body cells.

Osmoregulation and The Kidneys

☐ That homeostasis controls the water content of the blood to prevent body cells from bursting or shrinking due to changes in osmotic conditions.

☐ The structure of the urinary system — kidneys, renal vein and artery, ureters, bladder and urethra.

☐ That urea is produced from the breakdown of excess amino acids in the liver.

☐ How kidney nephrons filter the blood to remove waste substances (forming urine) and selectively reabsorb useful substances, and how the structure of the nephrons (including features such as the glomerulus, Bowman's capsule, loop of Henle and collecting duct) allow them to do this.

☐ **H** That anti-diuretic hormone (ADH) makes the collecting ducts of the kidney nephrons more permeable to water and so increases the amount of water reabsorbed into the blood.

Kidney Failure

☐ How kidney failure can be treated using dialysis and organ donation.

Exam-style Questions

1 Kaye has recently been diagnosed with type 1 diabetes.

(a) Which of the following statements about type 1 diabetes is true?

A People with type 1 diabetes are advised to eat a high sugar diet.

B Type 1 diabetes allows the blood glucose concentration to get too high.

C Type 1 diabetes is caused by the liver and stomach failing to produce vital hormones.

D Type 1 diabetes is directly caused by the overproduction of testosterone.

(1 mark)

Kaye's doctor prescribed her hormone injections to control her condition.

(b) Name the hormone that the injections will contain.

(1 mark)

(c) Explain why injecting this hormone can be an effective treatment for type 1 diabetes.

(3 marks)

2 The kidneys control the water and ion content of the blood.

(a) Which hormone controls the regulation of water content?

A ADH **B** LH

C thyroxine **D** adrenaline

(1 mark)

(b) Excess water is excreted from the body in urine.
Describe how urine is produced in the kidney nephrons.

(3 marks)

Figure 1 shows the concentration of sodium ions in the blood and urine of a healthy individual after a large meal.

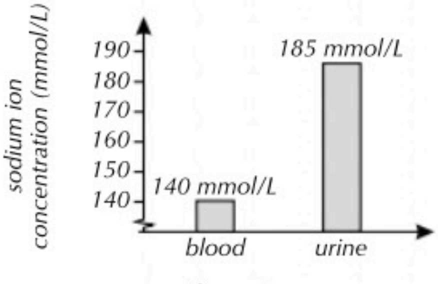


Figure 1

(c) Describe and explain the difference between the concentration of sodium ions in the blood and the concentration of sodium ions in the urine of the individual.

(2 marks)

1. Exchange of Materials

Living organisms need to be able to exchange substances with their environment in order to survive. An organism's size and surface area affect how quickly this is done.

Movement of substances

All organisms must take in substances they need for life processes from the environment. They must also get rid of any waste products from these processes. For example:

- Cells need oxygen for aerobic respiration (see page 270), which produces carbon dioxide as a waste product. These two gases move between cells and the environment by diffusion (see pages 48-49).
- Water is taken up by cells by osmosis (see pages 49-50). In animals, dissolved food molecules (the products of digestion, e.g. glucose, amino acids) and mineral ions diffuse along with it.
- Urea (a waste product produced by animals from the breakdown of proteins, see p.246) diffuses from cells into the blood plasma for removal from the body by the kidneys.

How easy it is for an organism to exchange substances with its environment depends on the organism's surface area to volume ratio (SA : V).

Surface area to volume ratios

A **ratio** shows how big one value is compared to another. The larger an organism is, the smaller its surface area is compared to its volume. You can show this by calculating surface area to volume ratios. To do that, you first need to know an organism's volume and surface area. The easiest way to find them is to estimate the size of the organism in the form of a block.

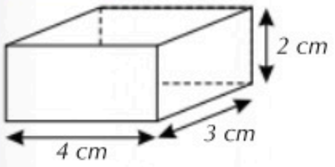
Calculating volume and surface area

The volume of a block (e.g. a cube or cuboid) is found by the equation:

volume = length × width × height

Example

MATHS SKILLS



A block that measures 4 cm by 3 cm by 2 cm has the volume:

4 cm × 3 cm × 2 cm = **24 cm^3**

Learning Objectives:

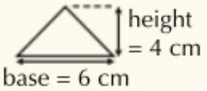
- Be able to describe the need to transport substances into and out of a range of organisms, including oxygen, carbon dioxide, water, dissolved food molecules, mineral ions and urea.
- Be able to explain the need for exchange surfaces and a transport system in multicellular organisms including the calculation of surface area : volume ratio.

Specification References 8.1, 8.2

Tip: Dissolved substances can also move to where they need to be by active transport (see p.51).

Tip: The units of volume are given in units cubed (e.g. μm^3).

Tip: The area of a triangle is found by the equation:
$\frac{1}{2} \times \text{height} \times \text{base}$.
E.g.



Area = $\frac{1}{2} \times 4\text{ cm} \times 6\text{ cm}$
$= 12\text{ cm}^2$

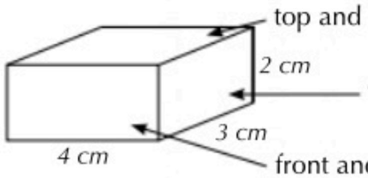
The area of a square or rectangular surface is found by the equation:

$$\text{area} = \text{length} \times \text{width}$$

To calculate the surface area of an object, just calculate the area of each side and add them all together.

Example

A block that measures 4 cm by 3 cm by 2 cm has six surfaces:



top and bottom: $4\text{ cm} \times 3\text{ cm} = 12\text{ cm}^2$

two sides: $3\text{ cm} \times 2\text{ cm} = 6\text{ cm}^2$

front and back: $4\text{ cm} \times 2\text{ cm} = 8\text{ cm}^2$

So the total surface area of the block is:
$12 + 12 + 6 + 6 + 8 + 8 = \mathbf{52\text{ cm}^2}$

Tip: The units of area are given in units squared (e.g. μm^2).

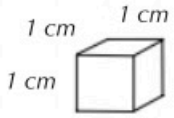
Comparing surface area to volume ratios

Here's how to calculate surface area to volume ratios:

Tip: To write a ratio, you just need to write the number of one thing compared to the number of another thing, separated by a colon.

Example

A mouse can be represented by a cube measuring 1 cm × 1 cm × 1 cm.



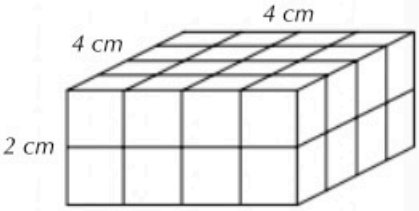
"cube mouse"

Its volume is: $1 \times 1 \times 1 = 1\text{ cm}^3$

Its surface area is: $6 \times (1 \times 1) = 6\text{ cm}^2$

So the mouse has a surface area : volume ratio of **6 : 1**.

Compare this to a cube hippo measuring 2 cm × 4 cm × 4 cm.



"cube hippo"

Its volume is: $2 \times 4 \times 4 = 32\text{ cm}^3$

Its surface area is:

$2 \times (4 \times 4) = 32\text{ cm}^2$
(top and bottom surfaces)

$+ (4 \times 2) \times 4 = 32\text{ cm}^2$ (four sides)

Total surface area = 64 cm^2

The surface area to volume ratio of the hippo can be written as 64 : 32.

To get the ratio in the form n : 1, divide both sides of the ratio by the volume.

So the hippo has a surface area : volume ratio of **2 : 1**.

Tip: To compare two ratios, it's easier if you write both of them in the form n : 1. There's more about writing and simplifying ratios on page 325.

Now you can compare the ratios:

The cube mouse's surface area is six times its volume, but the cube hippo's surface area is only twice its volume. So the mouse has a larger surface area compared to its volume.

Figure 1: *A hippo (top) has a small surface area:volume ratio. A mouse (bottom) has a large surface area:volume ratio.*

Why are exchange surfaces needed?

In single-celled organisms, gases and dissolved substances can diffuse directly into (or out of) the cell across the cell membrane. It's because they have a large surface area compared to their volume, so enough substances can be exchanged across the membrane to supply the volume of the cell.

Multicellular organisms (such as animals) have a smaller surface area compared to their volume. This makes it difficult to exchange enough substances to supply their entire volume across their outside surface alone. This means they need some sort of **exchange surface** for efficient diffusion and a transport system to move substances between the exchange surface and the rest of the body.

Example

Oxygen is able to diffuse from the air into a bacterial cell across the cell surface. A bacterium can get all the oxygen it needs for respiration this way.

But in the human body, there are trillions of cells and they all need to get enough oxygen to respire. Oxygen can't just diffuse in through your skin — it would never reach the cells deep inside you.

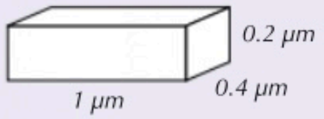
So humans need a specialised gas exchange surface (the alveoli, see p.260) for the oxygen to diffuse across and a specialised breathing system to get it there. They also need a circulatory system (see pages 262-269) to transport the oxygen to every cell.

Tip: One trillion is 10^{12} or 1 000 000 000 000. I wonder who counted all those cells...

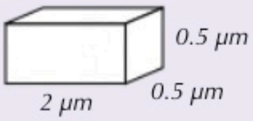
Practice Question — Application

Q1 Two different cells can be represented by the shapes below:

A



B



Tip: These cells are not drawn to scale.

a) Calculate the surface area to volume ratio for each cell. Write each ratio in the form n : 1.

b) Predict which cell is most efficient at absorbing substances by diffusion. Explain your answer.

Learning Objectives:

- Be able to describe the factors affecting the rate of diffusion, including surface area, concentration gradient and diffusion distance.
- Be able to calculate the rate of diffusion using Fick's law: rate of diffusion $\propto$ (surface area × concentration difference) ÷ thickness of membrane.

Specification References
8.4B, 8.5B

2. Factors Affecting the Rate of Diffusion

On the previous few pages, you looked at the importance of diffusion in the transport of substances into and out of organisms. On this page you'll see how the rate of diffusion is affected by different factors.

The rate of diffusion

The rate of diffusion of any substance is affected by these three factors:

- Surface area — the more surface there is available for molecules to move across, the faster they can get from one side to the other.
- Concentration difference (gradient) — substances diffuse faster if there is a big difference in concentration between the area they are diffusing from and the area they are diffusing to. If there are lots more particles on one side, there are more there to move across.
- Distance to move — substances diffuse more quickly when they haven't as far to move. The thinner the exchange surface (e.g. a cell membrane) the shorter the distance substances have to diffuse across it — and so the faster the rate of diffusion. The posh way of saying this is that the substances have a 'short diffusion pathway'.

To ensure that substances can be effectively exchanged, exchange surfaces are adapted to maximise the rate of diffusion — there's an example of this on page 261.

Tip: Substances diffuse from an area of higher concentration to an area of lower concentration (see p.48).

Tip: Imagine diffusion like a group of people moving between one room and another. People will move at a faster rate from one room to the other through a short, wide corridor, compared to people moving through a long narrow corridor. They will also be more likely to move if they are going from a very crowded room to a more spacious room.

Fick's law

The relationship between the rate of diffusion and the factors that affect it is described by Fick's law. It states that:

$$\text{rate of diffusion} \propto \frac{\text{surface area} \times \text{concentration difference}}{\text{thickness of membrane}}$$

$\propto$ is the 'proportional to' symbol (see page 328). It means that the rate of diffusion increases in proportion to (at the same rate as) the surface area or concentration difference and in inverse proportion to the thickness of the membrane. Essentially, what this means is that the rate of the diffusion will double if:

- the surface area or the difference in concentration doubles, OR
- the thickness of the membrane halves.

Likewise, if you treble the surface area or difference in concentration, the rate will treble. If you double the thickness of the membrane, the rate of diffusion will halve.

Tip: Inverse proportion means that as one value increases, the other decreases at the same rate. You might remember it from the inverse square law on page 206.

You can use (surface area × concentration difference) ÷ thickness of membrane as a measure of the rate of diffusion.

Example

An exchange surface has a surface area of 11 μm^2.
It is 0.01 μm thick. The concentration of oxygen on one side of the exchange surface is 0.4 M. The concentration on the other side is 0.2 M.

- Use the formula:

$$\text{rate of diffusion} = \frac{\text{surface area} \times \text{concentration difference}}{\text{thickness of membrane}}$$

- Fill in the values you know.
  You can work out the concentration difference by taking the smaller concentration away from the larger concentration.

$$\text{rate of diffusion} = \frac{11 \times (0.4 - 0.2)}{0.01}$$

- Calculate the answer: rate of diffusion = **220 a.u.**

Tip: a.u. stands for 'arbitrary units'.

Practice Questions — Fact Recall

Q1 Give three factors that increase the rate of diffusion.

Q2 How does halving the thickness of a membrane affect the rate of diffusion through that membrane?

Practice Question — Application

Q1 An exchange surface has a surface area of 80 μm^2 and a thickness of 2 μm. There is a difference of 0.5 M between the concentrations of dissolved carbon dioxide on either side of the exchange surface.

Use Fick's law to calculate the rate of diffusion of carbon dioxide. Give your answer in arbitrary units (a.u.).

3. The Alveoli

In humans (and other mammals), gases are exchanged by diffusion in little air sacs in the lungs called alveoli.

Learning Objective:

- Be able to explain how alveoli are adapted for gas exchange by diffusion between air in the lungs and blood in the capillaries.

Specification Reference 8.3

Gas exchange in mammals

The job of the lungs is to transfer oxygen (O_2) to the blood and to remove waste carbon dioxide (CO_2) from it. To do this the lungs contain millions of little air sacs called **alveoli** (see Figure 1) where gas exchange takes place.

Tip: Gas exchange in animals means taking in oxygen from the environment and releasing carbon dioxide.

Tip: It's one alveolus and two or more alveoli.

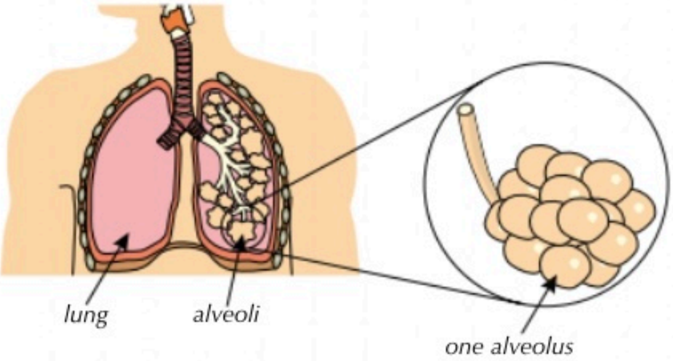


Figure 1: *Diagram to show the location and structure of the alveoli.*

The alveoli are surrounded by a network of tiny blood vessels known as capillaries (see Figure 2). Blood arriving at the alveoli has just returned to the lungs from the rest of the body, so it contains lots of carbon dioxide and not much oxygen. This maximises the **concentration gradient** for the diffusion of both gases:

- There is a higher concentration of oxygen in the air than in the blood, so oxygen diffuses out of the air in the alveoli and into the blood in the capillaries.
- Carbon dioxide diffuses in the opposite direction, from a high concentration in the blood to a low concentration in the alveoli (see Figure 4), to be breathed out.

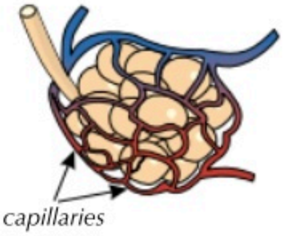


Figure 2: *The alveoli are surrounded by a network of capillaries.*

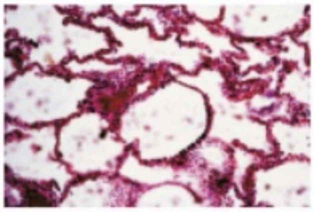


Figure 3: *Alveoli and surrounding capillaries as seen under a light microscope.*

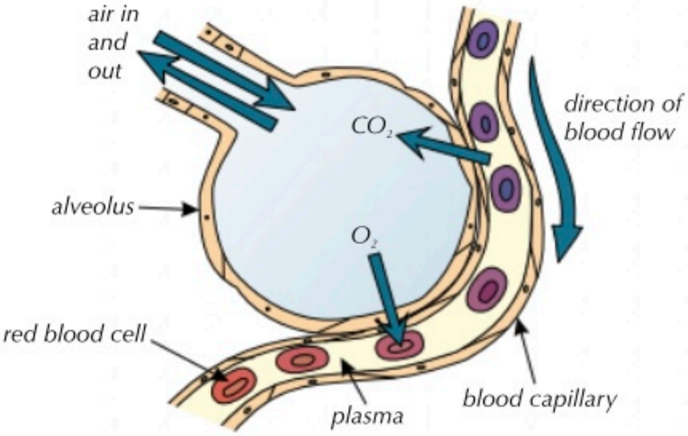


Figure 4: *Diagram to show gas exchange across an alveolus.*

Adaptations of the alveoli

The alveoli are specialised to maximise the diffusion of oxygen and CO_2. They have:

- An enormous surface area (about 75 m^2 in humans).
- A moist lining for dissolving gases — the gases need to be dissolved before they can diffuse through the alveolar walls.
- Very thin walls.
- A good blood supply to maintain the concentration gradients of oxygen and carbon dioxide.

Tip: Oxygen and carbon dioxide diffuse across the membranes of the cells that make up the walls of the capillary and alveolus. These membranes are partially permeable — see p.48.

Practice Questions — Fact Recall

Q1 Name the structures in the lungs where gas exchange takes place.

Q2 In which direction does oxygen diffuse in the lungs?

A From the capillaries into the alveoli.

B From the alveoli into the capillaries.

Explain your answer.

Q3 Give three ways in which the alveoli are adapted to maximise the diffusion of oxygen and carbon dioxide.

Practice Question — Application

Q1 Chronic obstructive pulmonary disease (COPD) can be caused by long-term exposure to irritants which results in destruction of the alveolar walls.

Suggest how COPD will affect gas exchange in the lungs. Explain your answer.

4. Circulatory System — The Blood

Learning Objective:

- Be able to explain how the structure of the blood is related to its function, including: red blood cells (erythrocytes), white blood cells (phagocytes and lymphocytes), platelets and plasma.

Specification Reference 8.6

Blood is a major component of the circulatory system. It is used by multicellular organisms to transport materials between their cells.

Function of the circulatory system

The circulatory system's main function is to get food and oxygen to every cell in the body. As well as being a delivery service, it's also a waste collection service — it carries waste products like carbon dioxide and urea to where they can be removed from the body. The circulatory system includes the blood, blood vessels and the heart.

What is blood?

Blood is a tissue — it's a group of similar cells which work together to perform a specific function. The function of the blood is to transport substances around the body. It's made up of **red blood cells**, **white blood cells** and **platelets**, which are all suspended in a liquid called **plasma**.

Red blood cells

The job of red blood cells (also called **erythrocytes**) is to transport oxygen around the body. They have a biconcave disc shape (see Figure 1) to give them a large surface area for absorbing oxygen. They also contain a red pigment called **haemoglobin**, which contains iron. The haemoglobin carries the oxygen.

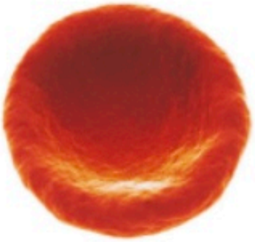


Figure 1: *A red blood cell has a biconcave shape — it looks like it's been squashed in the middle on both sides.*

Red blood cells are different from most types of animal cell because they don't have a nucleus — this allows more room for haemoglobin, which means they can carry more oxygen.

Transporting oxygen

All body cells need oxygen for respiration — a process which releases energy (see pages 270-272). Oxygen enters the lungs when you breathe in, then red blood cells transport the oxygen from the lungs to all the cells in the body:

- In the lungs, oxygen diffuses into the blood. The oxygen combines with haemoglobin in red blood cells to become oxyhaemoglobin (see Figure 2).
- In body tissues, the reverse happens — oxyhaemoglobin splits up into haemoglobin and oxygen, to release oxygen to the cells.

Tip: The more red blood cells you've got, the more oxygen can get to your cells. At high altitudes there's less oxygen in the air — so people who live there produce more red blood cells to compensate.

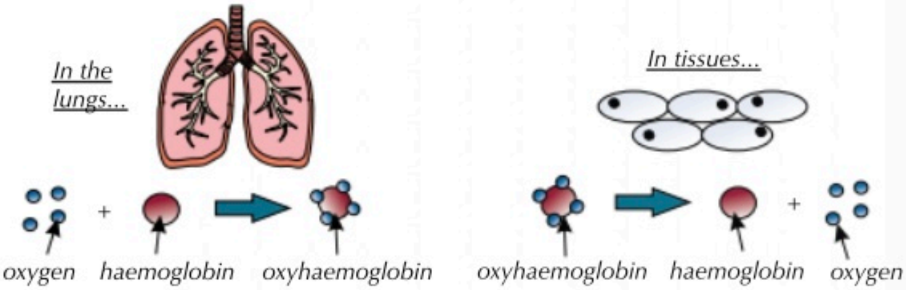


Figure 2: *Diagram illustrating the formation and breakdown of oxyhaemoglobin.*

White blood cells

Unlike red blood cells, white blood cells have a nucleus. White blood cells help to defend against microorganisms that cause disease (see pages 164-166). There are different types of white blood cell. For example:

- **Phagocytes** are white blood cells that change shape to engulf unwelcome microorganisms — this is called phagocytosis.
- **Lymphocytes** are a group of white blood cells that have different functions depending on their type. For example, B lymphocytes produce antibodies against microorganisms (see p.165). Some also produce antitoxins to neutralise any toxins produced by the microorganisms.

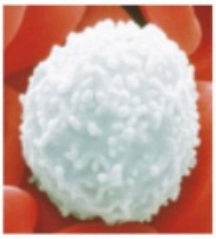


Figure 3: *A white blood cell.*

When you have an infection, your white blood cells multiply to fight it off — so a blood test will show a high white blood cell count.

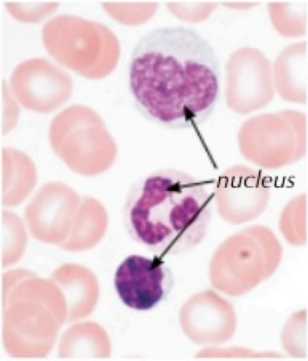


Figure 4: *A picture taken down a light microscope showing three different types of white blood cell (stained purple) surrounded by red blood cells (pale red).*

Platelets

Platelets are small fragments (pieces) of cells. They have no nucleus. They help the blood to **clot** (clump together) at a wound — this seals the wound and stops you from losing too much blood (see Figure 5). It also stops microorganisms from getting in at the wound. A lack of platelets can cause excessive bleeding and bruising.

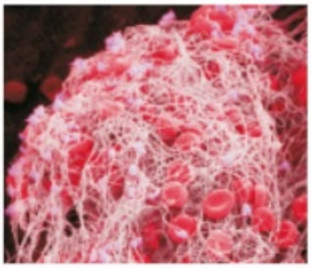


Figure 5: *A blood clot formed by the action of platelets.*

Plasma

Plasma is a pale straw-coloured liquid which carries just about everything in blood. It carries:

- Red and white blood cells and platelets.
- Nutrients like glucose and amino acids. These are the soluble products of digestion, which are absorbed from the small intestine and taken to the cells of the body.
- Carbon dioxide from the organs to the lungs.
- Urea from the liver to the kidneys.
- Hormones.
- Proteins.
- Antibodies and antitoxins produced by the white blood cells.

Figure 6: *A pouch of plasma, which has been extracted from donated blood.*

Tip: Urea is a waste product produced from the breakdown of amino acids in the liver.

Practice Questions — Fact Recall

Q1 a) Name the red pigment found in red blood cells.

b) Describe the role of this red pigment.

Q2 What is the function of white blood cells?

Q3 What is the role of platelets?

Q4 Name the part of blood that's used to transport cells and platelets.

Learning Objective:

- Be able to explain how the structure of the blood vessels is related to their function.

Specification Reference 8.7

5. Circulatory System — The Blood Vessels

Our blood makes its way around our body in blood vessels. There are three different types of blood vessels you need to know about...

Arteries

Arteries are blood vessels which carry blood away from the heart, towards the organs. The heart pumps the blood out at high pressure, so the artery walls are strong and elastic. They contain thick layers of muscle to make them strong, and elastic fibres to allow them to stretch and spring back. The walls are thick compared to the size of the hole down the middle (the lumen) — see Figure 1.

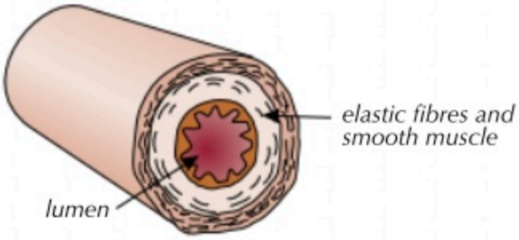


Figure 1: *Diagram to show the structure of an artery.*

Capillaries

Arteries branch into capillaries. Capillaries are involved in the exchange of materials at the tissues — they carry the blood really close to every cell in the body to exchange substances with them. They supply food and oxygen to the cells, and take away waste products like carbon dioxide.

Tip: Remember, diffusion is the process by which substances move from an area of higher concentration to an area of lower concentration.

Capillaries are really tiny — too small to see. They have permeable walls, so the substances being exchanged with the cells can diffuse in and out. Their walls are usually only one cell thick (see Figure 3). This increases the rate of diffusion by decreasing the distance over which it occurs. Capillaries are also very narrow, so they can squeeze into the gaps between cells. It also gives them a large surface area compared to their volume, which increases the rate of diffusion.

Figure 2: *A torn capillary with blood cells leaking out — you can see how thin the walls of the capillary are.*

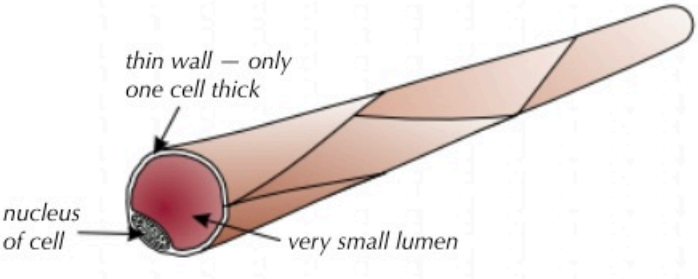


Figure 3: *Diagram to show the structure of a capillary.*

Veins

Capillaries eventually join up to form veins. Veins carry blood to the heart.

The blood is at lower pressure in the veins, so the walls don't need to be as thick as artery walls. Veins have a bigger lumen than arteries to help the blood flow despite the lower pressure (see Figure 4).

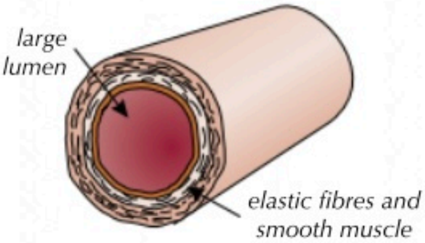


Figure 4: *Diagram to show the structure of a vein.*

They also have **valves** to help keep the blood flowing in the right direction to prevent backflow (see Figure 6).

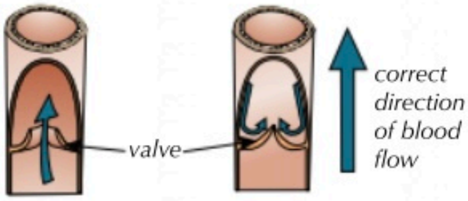


Figure 6: *Diagram to show how valves prevent the backflow of blood.*

Exam Tip
If you're struggling to remember which way arteries and veins carry blood in the exam, think: arteries are the 'way art' (way out) of the heart, and veins are the 'vey in' (way in).

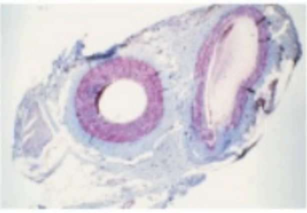


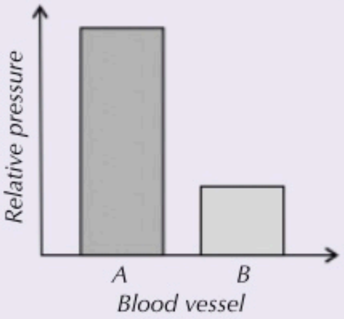
Figure 5: *A cross-section through an artery and a vein — the walls of the blood vessels are pink. The walls of the artery (left) are much thicker than the walls of the vein (right).*

Practice Question — Fact Recall

Q1 What type of blood vessel has walls that are only one cell thick?

Practice Question — Application

Q1 The graph below shows the relative pressure inside two different blood vessels — one is a vein and one is an artery.



Which blood vessel (A or B) would you expect to contain a higher proportion of muscle tissue in its walls? Explain your answer.

6. Circulatory System — The Heart

Learning Objectives:

- Be able to explain how the structure of the heart and circulatory system is related to its function, including the role of the major blood vessels, the valves and the relative thickness of chamber walls.
- Be able to calculate heart rate, stroke volume and cardiac output, using the equation:
  cardiac output = stroke volume × heart rate

Specification References
8.8, 8.12

The heart plays a major role in the circulatory system. It is needed to pump the blood through the blood vessels so that material can be transported to and from the cells.

Types of circulatory system

There are different types of circulatory system. In all types of circulatory system, a heart is needed to pump blood around the body.

A double circulatory system

Mammals (including humans) have a double circulatory system. This means that the heart pumps blood around the body in two circuits.

- In the first circuit, the heart pumps deoxygenated blood (blood low in oxygen) to the lungs to take in oxygen. The oxygenated blood then returns to the heart (see Figure 1a).
- In the second circuit, the heart pumps oxygenated blood around all the other organs of the body. The blood gives up its oxygen at the body cells and the deoxygenated blood returns to the heart to be pumped out to the lungs again (see Figure 1b).

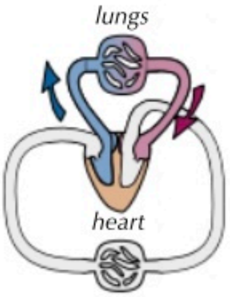


Figure 1a: *Blood circulation between the heart and the lungs in mammals.*

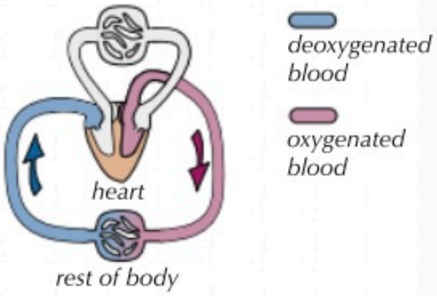


Figure 1b: *Blood circulation between the heart and the rest of the body in mammals.*

A single circulatory system

Fish have a single circulatory system. Deoxygenated blood from the fish's body travels to the heart, which then pumps it right round the body again in a single circuit. The blood goes via the gills where it picks up oxygen. In single circulatory systems, only deoxygenated blood goes through the heart (see Figure 2).

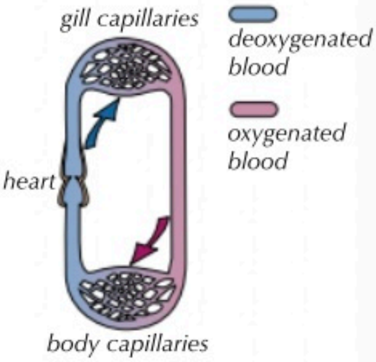


Figure 2: *Blood circulation in a fish.*

The blood pressure in single circulatory systems is limited to prevent damage to the capillaries in the gills. In a double circulatory system, blood can be pumped at a low safe pressure in the circuit to the lungs, and at a higher pressure in the circuit to the rest of the body (so material in the blood can reach the cells faster).

Structure of the mammalian heart

The mammalian heart has four chambers (the **right atrium**, **right ventricle**, **left atrium** and **left ventricle**) which it uses to pump blood around (see Figure 3). The major blood vessels leading into and out of these chambers are the **vena cava**, **pulmonary artery**, **aorta** and **pulmonary vein**. The walls of the heart are mostly made of muscle tissue, which contracts to pump the blood.

Exam Tip
You need to learn the names of these chambers and the main blood vessels leading into and out of the heart for your exam.

Tip: A fish's heart only has two chambers — a ventricle and an atrium.

Tip: Don't be confused about the way the right and left side of the heart are labelled in this diagram — this is the right and left side of the person whose heart it is.

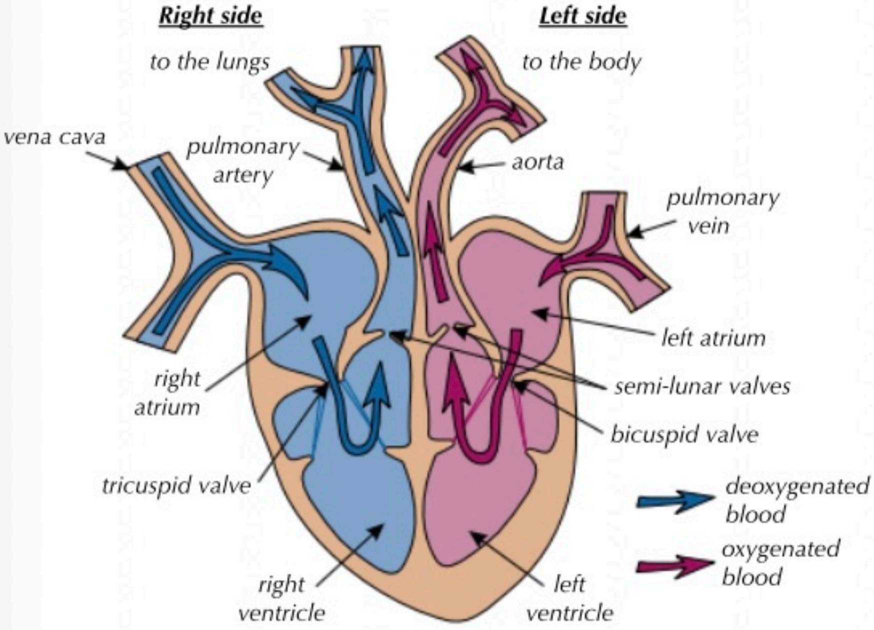

Right side
Left side
to the lungs
to the body
vena cava
pulmonary artery
aorta
pulmonary vein
left atrium
semi-lunar valves
bicuspid valve
right atrium
tricuspid valve
deoxygenated blood
oxygenated blood
right ventricle
left ventricle

Figure 3: Diagram showing the structure of the heart and the direction of blood flow through the heart.

The heart has **valves** to make sure that blood goes in the right direction — they prevent it flowing backwards.

Tip: The heart also needs its own supply of oxygenated blood. Arteries called coronary arteries branch off the aorta and surround the heart, making sure that it gets all the oxygenated blood it needs. If they become blocked, the heart can become starved of oxygen, potentially leading to a heart attack (see p.192).

Blood flow through the heart

Deoxygenated blood flows through the right side of the heart to the lungs. Oxygenated blood flows through the left side of the heart to the rest of the body.

1. The right atrium of the heart receives deoxygenated blood from the body through the vena cava (see Figure 4 on the next page). The left atrium receives oxygenated blood from the lungs through the pulmonary vein.

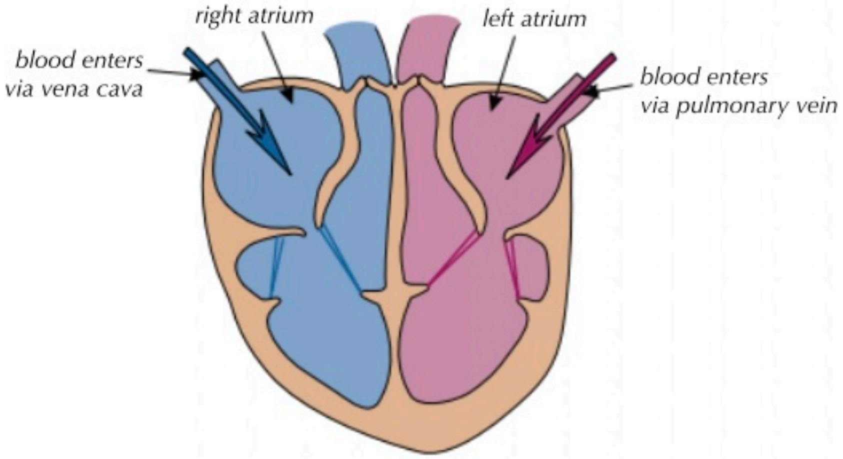

right atrium
left atrium
blood enters via vena cava
blood enters via pulmonary vein

Figure 4: *Diagram showing blood flowing into the heart.*

Tip: 'Atria' is the plural of 'atrium'. So you get one atrium, but two atria.

2. The atria contract, pushing the blood into the ventricles.
3. The ventricles contract. Deoxygenated blood moves from the right ventricle to the lungs via the pulmonary artery. The oxygenated blood moves from the left ventricle to the whole body via the aorta (see Figure 5).

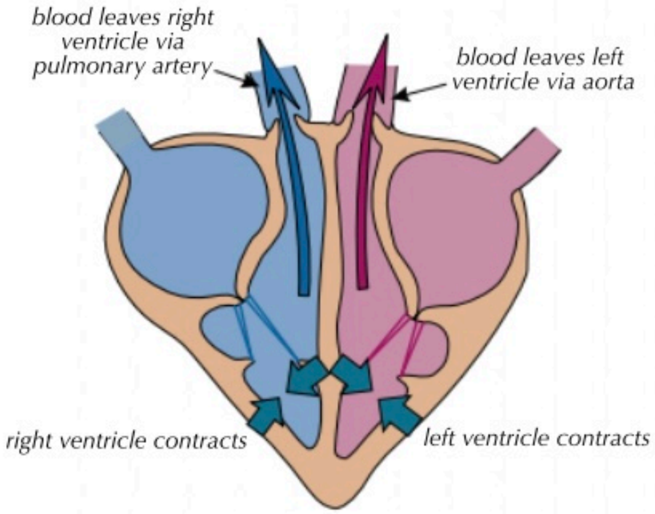

blood leaves right ventricle via pulmonary artery
blood leaves left ventricle via aorta
right ventricle contracts
left ventricle contracts

Figure 5: *Diagram showing blood being forced out of the heart.*

Thickness of the chamber walls

The thickness of each chamber wall in the heart is related to its function.

Both atria walls are relatively thin. They only need to pump blood a short distance to the ventricles, so they don't require much muscle.

The ventricles have to pump blood further, so their chamber walls are thicker than those of the atria. The wall of the left ventricle is much thicker than the wall of the right ventricle. This is because the left ventricle needs more muscle to pump blood around the whole body at high pressure, whereas the right ventricle only has to pump blood to the lungs.

Calculating cardiac output

Cardiac output is the total volume of blood pumped by a ventricle every minute. You can calculate it using this equation:

cardiac output = heart rate × stroke volume

in cm^3 min^{-1} in beats per minute (bpm) in cm^3

The **heart rate** is the number of beats per minute (bpm). The **stroke volume** is the volume of blood pumped by one ventricle each time it contracts.

Example

Calculate the cardiac output of a person with a heart rate of 68 bpm and an average stroke volume of 70 cm^3.

cardiac output (cm^3 min^{-1}) = heart rate (bpm) × stroke volume (cm^3)
= 68 × 70
= **4760 cm^3 min^{-1}**

Tip: A cardiac output of 4760 cm^3 min^{-1} means that 4760 cm^3 of blood are pumped by a ventricle in 1 minute.

You might be asked to find the stroke volume or the heart rate in the exam instead of the cardiac output — if so, you can just rearrange the equation above.

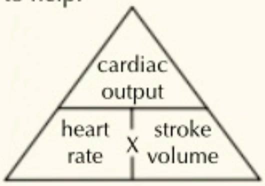
Example

What is the heart rate of a person with an average stroke volume of 72 cm^3 and a cardiac output of 5420 cm^3 min^{-1}?

heart rate (bpm) = cardiac output (cm^3 min^{-1}) ÷ stroke volume (cm^3)
= 5420 ÷ 72
= **75 bpm**

Exam Tip

If you find rearranging formulas hard, you can use a formula triangle to help:



All you do is put your finger over the one you want and read off the formula. E.g. if you want the heart rate, you put your finger over that and it leaves behind cardiac output ÷ stroke volume.

Practice Questions — Fact Recall

Q1 The circulatory system in mammals is made up of two separate circuits. What is the function of each circuit?

Q2 Name the four chambers of the mammalian heart.

Q3 Name the two blood vessels which:

a) carry blood into the heart, b) carry blood out of the heart.

Practice Questions — Application

Q1 Alan has a condition known as SVCS. This condition is very serious as it obstructs blood flow in the vessel going into the heart from the rest of the body. Name the blood vessel which is affected in SVCS.

Q2 A man has a heart rate of 85 bpm and a cardiac output of 6.46 dm^3 min^{-1}. Calculate the man's stroke volume in cm^3.

Exam Tip

Make sure you check the units of measurements you're given in the exams. You may need to convert them before you carry out a calculation with them. See p.19-20 for more on converting units.

7. Respiration

We, and other organisms, need energy to do... well... everything really. This energy comes from the reactions of respiration.

Learning Objectives:

- Be able to describe cellular respiration as an exothermic reaction which occurs continuously in living cells to release energy for metabolic processes, including aerobic and anaerobic respiration.
- Be able to compare the process of aerobic respiration with the process of anaerobic respiration.

Specification References
8.9, 8.10

What is respiration?

Respiration is not breathing in and breathing out, as you might think. It's a process that goes on continuously in every cell of all living organisms. For this reason, it's also known as cellular respiration.

Cellular respiration is the process of transferring (releasing) energy from the breakdown of organic compounds (usually glucose). This energy is used to fuel metabolic processes — the necessary chemical reactions that take place inside living organisms. Because energy is transferred to the environment, respiration is an **exothermic reaction**. Some of this energy is transferred by heat. In summary:

> Cellular respiration is an exothermic reaction, which releases energy for metabolic processes, and occurs continuously in every cell of living organisms.

There are two types of respiration — aerobic and anaerobic.

Tip: Organic compounds are compounds containing carbon. They include carbohydrates, lipids and proteins.

Energy from respiration

Organisms use the energy transferred by respiration to fuel all sorts of metabolic processes.

Examples

- Organisms use energy for reactions that involve building up larger molecules from smaller ones (like proteins from amino acids).
- Animals use energy in the chemical reactions that allow their muscles to contract (which in turn allows them to move about).
- Mammals and birds use energy to keep their body temperature steady (unlike other animals, mammals and birds keep their bodies constantly warm).

Tip: Respiration itself is a metabolic process.

Figure 1: *Animals, including humans, need energy from respiration to contract their muscles and move.*

Aerobic respiration

Aerobic respiration is respiration using oxygen. It's the most efficient way to transfer energy from glucose. Aerobic respiration goes on all the time in plants and animals.

Most of the reactions in aerobic respiration happen inside cell structures called **mitochondria** (see page 23).

Word equation

You need to learn the overall word equation for aerobic respiration:

glucose + oxygen → carbon dioxide + water

Tip: The equations for aerobic respiration are the reverse of the photosynthesis equations (see p.199).

Symbol equation

There's a symbol equation for aerobic respiration too:

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$$

Anaerobic respiration

When you do vigorous exercise, your body can't supply enough oxygen to your muscles for aerobic respiration, even though your heart rate and breathing rate increase as much as they can. So your muscles have to start respiring anaerobically as well.

Tip: An increased breathing rate gets more oxygen into your lungs. An increased heart rate means that blood is pumped round the body faster, so the cells receive oxygen more quickly.

"Anaerobic" just means "without oxygen". It's the incomplete breakdown of glucose, making **lactic acid**. Here's the word equation for anaerobic respiration in animals:

glucose → lactic acid

Since glucose is only partially broken down, anaerobic respiration does not transfer nearly as much energy as aerobic respiration, making it much less efficient. So, anaerobic respiration is only useful in emergencies, e.g. during exercise when it allows you to keep on using your muscles for a while longer.

During vigorous exercise, lactic acid builds up in the muscles which gets painful and leads to cramp.

Anaerobic respiration in plants

Anaerobic respiration in plants is slightly different. Plants cells can respire without oxygen too, but they produce ethanol (alcohol) and carbon dioxide instead of lactic acid.

This is the word equation for anaerobic respiration in plants:

glucose → ethanol + carbon dioxide

Tip: Fungi, such as yeast, also respire anaerobically to produce ethanol and carbon dioxide. Anaerobic respiration in yeast is used to make beer.

Comparing aerobic and anaerobic respiration

You need to be able to compare aerobic and anaerobic respiration.

	Aerobic respiration	Anaerobic respiration
Is oxygen needed?	yes	no
What products are made?	CO_2 and water	lactic acid (animals) / CO_2 and ethanol (plants)
How much energy is transferred?	A large amount.	A small amount.

Figure 2: *Table comparing aerobic and anaerobic respiration.*

Practice Questions — Fact Recall

Q1 Give three ways in which mammals use energy from respiration.

Q2 What is aerobic respiration?

Q3 Aerobic respiration is an exothermic reaction.
What does this mean?

Q4 Explain when the body uses anaerobic respiration.

Q5 Give the word equation for anaerobic respiration in animals.

Practice Questions — Application

Q1 This diagram shows the equation for aerobic respiration.

$$\text{glucose} + \boxed{A} \rightarrow \text{carbon dioxide} + \boxed{B}$$

a) What is A in the equation?

b) What is B in the equation?

Q2 Rice is grown in flooded fields called paddy fields. There is very little oxygen available in flooded soils. Suggest why the roots of rice plants need a high tolerance for ethanol (a poison).

Exam Tip
Make sure you know the word equations for both aerobic an anaerobic respiration off by heart. They could get you easy marks in the exam.

8. Investigating Respiration

CORE PRACTICAL

The rate at which an organism respires will change depending on different factors. You can do an experiment to see how temperature affects the rate of respiration.

Measuring the rate of respiration

In aerobic respiration, organisms use up oxygen from the air. By measuring the amount of oxygen consumed by organisms in a given time, you can calculate their rate of respiration.

Here's an experiment which uses woodlice, a water bath and a piece of equipment called a **respirometer**. It allows you to measure the effect of temperature on the rate of respiration of the woodlice. (You could use germinating peas or beans instead of woodlice. Germinating seeds respire to provide energy for growth.)

1. Take two test tubes, each containing soda lime granules covered by a ball of cotton wool. Soda lime absorbs the carbon dioxide produced by the respiring woodlice in the experiment. The cotton wool stops both you and the woodlice coming into contact with the soda lime.
2. Place woodlice on top of the cotton wool in one tube. Add glass beads with the same mass as the woodlice to the control tube.
3. Set up the respirometer as shown in Figure 1, with the water bath set to 15 °C.

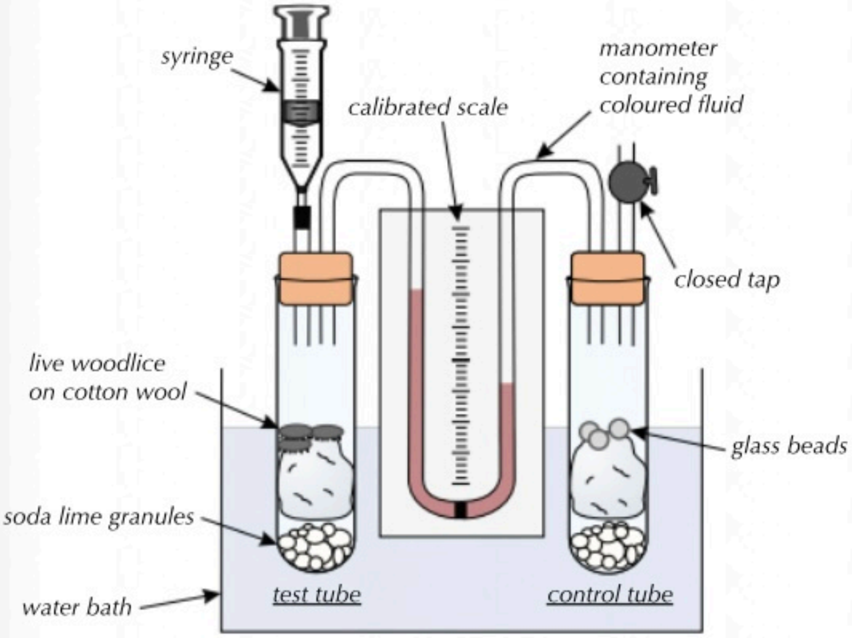


***Figure 1:** Apparatus for investigating the effect of temperature on respiration.*

Learning Objective:
- Be able to investigate the rate of respiration in living organisms. (Core Practical)

Specification Reference 8.11

Tip: Make sure that you carry out a risk assessment before you begin. Soda lime is corrosive, so your teacher or a lab technician should add it to the test tubes for you. Safety goggles and gloves should be worn during the experiment to protect the eyes and skin.

Tip: The control tube helps you check that the movement of the fluid in the respirometer (see next page) is caused by the woodlice respiring and not as a result of something else. There's more on controls on page 10.

Tip: There's more on using water baths on page 319.

Tip: You could also use cotton wool soaked in a few drops of potassium hydroxide solution to absorb the CO_2. You would need to prevent the woodlice from coming into contact with this though, e.g. by using a layer of gauze.

4. Leave the apparatus for 5 minutes to allow the temperature inside the test tubes to reach the temperature of the water bath.

5. Use the syringe to set the fluid in the manometer to a known level.

6. Leave the apparatus for a set period of time.

7. During this time, there'll be a decrease in the volume of the air in the test tube containing the woodlice. This is because the woodlice use up oxygen in the tube as they respire. (The carbon dioxide they produce is absorbed by the soda lime so it doesn't affect the experiment.)

8. The decrease in volume reduces the pressure in the tube, causing the coloured liquid in the manometer to move towards the test tube containing the woodlice. The higher the rate of respiration, the more the coloured liquid will move.

9. The distance moved by the liquid in a given time is measured. This value can then be used to calculate the volume of oxygen taken in by the woodlice per unit of time. This gives you the rate of respiration in, e.g. $cm^3\ min^{-1}$.

Tip: You can work out the volume of oxygen taken in by the woodlice by multiplying the distance moved by the liquid in the manometer by πr^2, where 'r' is the radius of the manometer.

Example

In an experiment measuring the respiration in woodlice, 2.7 cm^3 of oxygen were taken up in a 30 minute time period.

Calculate the rate of respiration in $cm^3\ min^{-1}$.

Divide the volume of oxygen taken up by the woodlice by the number of minutes that it was consumed in.

rate of respiration = $2.7 \div 30 =$ **0.09 $cm^3\ min^{-1}$**.

Exam Tip

Pay close attention to the units given in the question. Volume of oxygen uptake could be given in ml, mm^3 or cm^3. You could also be asked to calculate the rate of respiration per second — just divide the time in minutes by 60 and then follow the steps for working out the rate.

10. Repeat steps 1-9 with the water bath set at different temperatures, e.g. 20 °C and 25 °C. This will allow you to see how changing the temperature affects the rate of respiration.

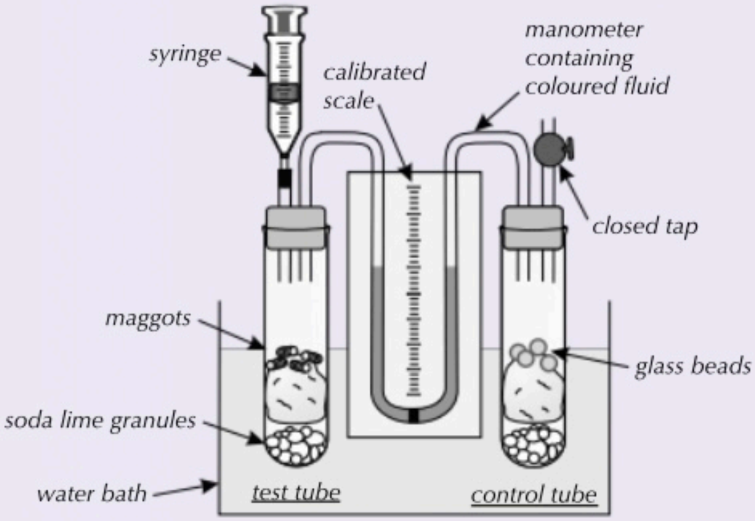
You should think carefully about what temperatures to use in your experiment before you start. The process of respiration uses enzymes. If the temperature is too high, enzymes will denature (see p.37) and so respiration will not occur. If you are using live animals, you also need to make sure you pick temperatures that are safe and do not cause discomfort (see below).

Ethical issues from using live organisms

Any live animals you use in this experiment should be treated ethically. For example, it's important not to leave the woodlice in the respirometer for too long, or they may run out of oxygen and die. They should also be kept away from the soda lime (or potassium hydroxide) as it is corrosive. There's more on the ethical treatment of organisms in experiments on page 323.

Practice Question — Application

Q1 A student carries out an investigation using a respirometer. Her experimental set-up is shown in the diagram below.


syringe
calibrated scale
manometer containing coloured fluid
closed tap
maggots
glass beads
soda lime granules
water bath
test tube
control tube

The student measures the rate of respiration in maggots over a 30 minute time period at 10 °C and then again at 20 °C. All other variables are kept the same.

a) What is the role of the cotton wool in the test tubes?

b) Explain why there is soda lime in the test tubes.

c) In which direction would you expect the coloured fluid in the manometer to move during the experiments?

A Towards the test tube containing maggots.

B Towards the control tube containing glass beads.

Explain your answer.

d) During the experiment at 20 °C, the fluid in the manometer moves further than the experiment at 10 °C. What does this suggest about the effect of temperature on the rate of respiration? Explain your answer.

Topic 8 Checklist — Make sure you know...

Exchange of Materials

☐ That organisms need to take in substances (e.g. oxygen, water, dissolved food molecules and mineral ions) from the environment for life processes, and that they need to remove the waste products (e.g. carbon dioxide and urea) from such processes.

☐ How to calculate and compare surface area to volume ratios.

☐ That exchanging materials with the environment is more difficult in multicellular organisms than in single-celled organisms due to their smaller surface area to volume ratios, so multicellular organisms need specialised exchange surfaces and transport systems for exchanging and carrying materials.

Factors Affecting the Rate of Diffusion

☐ That rate of diffusion is affected by the surface area available for molecules to move across, the concentration gradient and the thickness of the exchange surface (diffusion distance).

☐ How to use Fick's law to calculate the rate of diffusion:
rate of diffusion $\propto$ (surface area × concentration difference) ÷ thickness of membrane.

The Alveoli

☐ How alveoli (tiny air sacs) in the lungs are adapted to maximise the diffusion of oxygen into the blood and carbon dioxide out of the blood by having a large surface area, a moist lining, very thin walls and an efficient blood supply.

Circulatory System — The Blood

☐ That red blood cells (erythrocytes) have no nucleus, have a biconcave shape and contain haemoglobin that binds to oxygen, allowing them to carry oxygen from the lungs to the rest of the body.

☐ That white blood cells (e.g. phagocytes and lymphocytes) have a nucleus and help to defend against disease caused by microorganisms.

☐ That platelets are fragments of cells which don't have a nucleus and help blood to clot at a wound.

☐ That plasma carries just about everything in the blood including blood cells and platelets, nutrients released from digestion, carbon dioxide, urea, hormones, proteins, antibodies and antitoxins.

Circulatory System — The Blood Vessels

☐ That there are three types of blood vessel found in the body — arteries, which carry blood away from the heart, capillaries, which carry blood close to the cells to allow substances to be exchanged, and veins, which carry blood back to the heart.

☐ How the structures of the different blood vessels are adapted to allow them to carry out their roles in the circulatory system.

cont...

Circulatory System — The Heart

☐ That mammals (including humans have a double circulatory system to transport substances around the body via the blood, which is pumped around the body by the heart. One circuit, powered by the right ventricle, pumps deoxygenated blood to the lungs to take in oxygen, and the other circuit, powered by the left ventricle, pumps oxygenated blood to the rest of the body.

☐ That the four chambers of the mammalian heart are the right atrium, right ventricle, left atrium and left ventricle, that the thickness of a chamber wall is related to the chamber's function, and that the chambers have valves to prevent backflow.

☐ That the vena cava, pulmonary artery, aorta and pulmonary vein are the four major blood vessels connected to the heart.

☐ How to calculate heart rate, stroke volume and cardiac output, using the equation:
cardiac output = stroke volume × heart rate.

Respiration

☐ That respiration is an exothermic reaction, which releases energy for things such as metabolic processes, muscle contraction and maintaining body temperature, and that it occurs continuously in every cell of living organisms.

☐ That aerobic respiration is the process of transferring energy from glucose using oxygen in the reaction: glucose + oxygen → carbon dioxide + water, and that it occurs continuously in living cells.

☐ That muscles will start to respire anaerobically (without oxygen) if they can't get enough oxygen to respire aerobically, and that this involves the incomplete breakdown of glucose, which forms lactic acid: glucose → lactic acid. Anaerobic respiration transfers less energy than aerobic respiration.

☐ The word equation for anaerobic respiration in plants: glucose → ethanol + carbon dioxide.

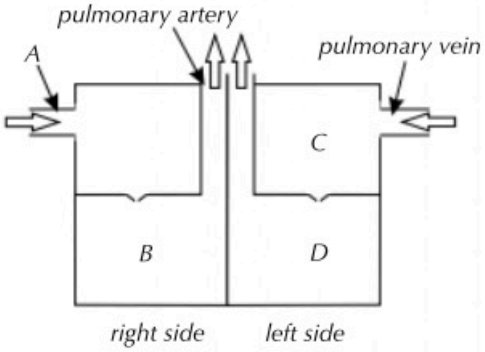
Investigating Respiration

☐ How to investigate the rate of respiration in living organisms. (Core Practical)

Exam-style Questions

1 **Figure 1** represents the heart.

Figure 1



(a) Name each of the structures labelled **A-C** on the diagram.

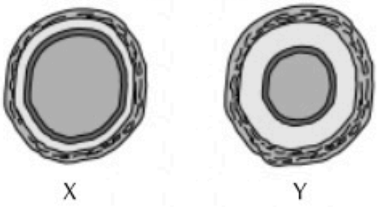
(3 marks)

(b) Explain why structure **D** has a thicker wall than structure **B**.

(2 marks)

Figure 2 shows cross-sections through the pulmonary artery and the pulmonary vein.

Figure 2



(c) Which diagram (**X** or **Y**) shows the pulmonary vein? Explain your answer.

(1 mark)

2 A doctor is looking at the blood test results for two patients. Their results, along with the normal range for each of the blood components tested, are shown in **Figure 3**:

Figure 3

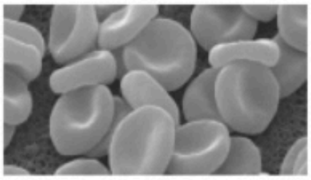
	Red Blood Cells (10^{12}/L)	White Blood Cells (10^9/L)	Platelets (10^9/L)	Urea (mmol/L)
Normal Range	3.9-5.6	4.0-11.0	150-400	3.0-7.0
Patient A	4.2	3.2	250	3.2
Patient B	3.7	10.2	315	5.4

(a) Explain which patient (**A** or **B**) is most at risk of getting an infection.

(2 marks)

(b) **Figure 4** shows a group of blood cells.

Figure 4



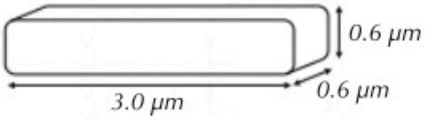
Identify the blood cells shown in **Figure 4** and explain **three** ways in which they are adapted to their function.

(4 marks)

3 Methods of exchanging substances with the environment vary between organisms. Some organisms contain specialised exchange surfaces for this purpose.

Figure 5 shows a rod-shaped bacterium, with its approximate dimensions.

Figure 5



(a) Calculate the surface area to volume ratio of this bacterium.

(3 marks)

(b) Explain why this bacterium doesn't need any specialised surfaces for exchanging substances with the environment.

(3 marks)

4 A scientist is investigating the reactions of aerobic and anaerobic respiration.

(a) State the word equation for aerobic respiration.

(2 marks)

(b) In a cell, energy is stored in a molecule called ATP.
The scientist conducts an experiment to find out how much ATP each type of respiration forms per glucose molecule.

His results are shown in **Figure 6**:

Figure 6

Type of respiration	Number of ATP molecules released per glucose molecule
Aerobic	32
Anaerobic	2

Using the table, describe and explain the difference in the amount of energy transferred by aerobic and anaerobic respiration.

(2 marks)

Topic 9a Ecosystems and Biodiversity

Learning Objectives:

- Be able to describe the different levels of organisation from individual organisms, populations and communities, to the whole ecosystem.
- Be able to describe the importance of interdependence in a community.
- Be able to describe how the survival of some organisms is dependent on other species, including parasitism and mutualism.

Specification References
9.1, 9.3, 9.4

1. Ecosystems and Interactions Between Organisms

Organisms live together in ecosystems. They depend on other organisms in their ecosystem for survival.

Important definitions

Topic 9 will make a lot more sense if you become familiar with these terms:

Habitat	The place where an organism lives, e.g. a field.
Population	All the organisms of one species living in a habitat.
Community	All the organisms of different species living in a habitat.
Abiotic factors	Non-living factors of the environment, e.g. temperature.
Biotic factors	Living factors of the environment, e.g. food.
Ecosystem	A community of organisms along with all the non-living (abiotic) parts of their environment.

Levels of organisation

There are different levels of organisation in an ecosystem (see Figure 1). The first and smallest level is an individual organism. Individual organisms make up a population (the next level of organisation) and several populations make up a community. The final and biggest level of organisation is the ecosystem itself.

individual
population
community
ecosystem

Figure 1: *Flow chart to show the levels of organisation in an ecosystem.*

Example

A fox is an individual organism. It may belong to a population of foxes living in a woodland habitat. The foxes are part of the community of other animals, birds, plants, trees and insects living in the same habitat. This community, along with abiotic factors such as the soil type, rainfall and light intensity in the woodland make up the ecosystem.

Tip: There's more on abiotic factors in ecosystems on p.283.

Interdependence

Organisms depend on each other for things like food and shelter in order to survive and reproduce. This is known as interdependence. It means that a change in the population of one species can have huge knock on effects for other species in the same community.

Example

Figure 2 shows part of a food web (a diagram of what eats what) from a stream.

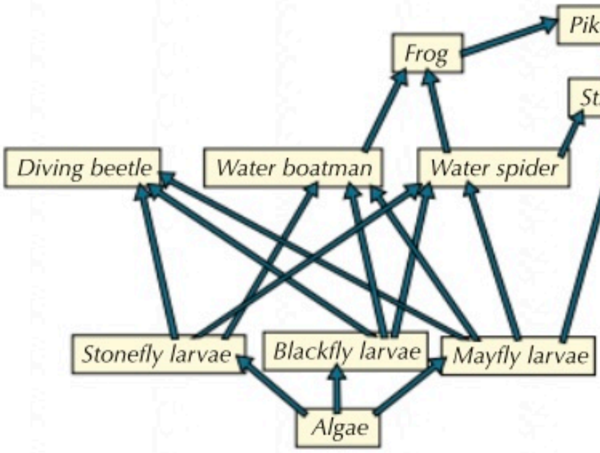


***Figure 2:** Diagram to show part of a food web in a stream.*

Tip: Imagine the arrows here mean 'is eaten by'. So the stonefly larvae is eaten by the diving beetle, the water boatman and the water spider.

Stonefly larvae are particularly sensitive to pollution. Suppose pollution killed them in this stream. The table below shows some of the effects this might have on some of the other organisms in the food web.

Organism	Effect of loss of stonefly larvae	Effect on population
Blackfly larvae	Less competition for algae	Increase
	More likely to be eaten by predators	Decrease
Water spider	Less food	Decrease
Stickleback	Less food (if water spider or mayfly larvae numbers decrease)	Decrease

Mutualism

Mutualism is an example of interdependence in ecosystems. It is a relationship between two organisms, from which both organisms benefit.

Examples

- Bees and flowering plants have a mutualistic relationship. Bees visit flowers to get nectar (a sugary liquid, which the bees eat). As they do so, pollen is transferred to the bees' bodies. The bees then spread the pollen to other plants when they land on their flowers. The bees get food and the plants get help reproducing — so both types of organism benefit.

***Figure 3:** A honeybee visiting a chrysanthemum flower. The yellow blob on the bee is pollen.*

- 'Cleaner fish' (such as cleaner wrasse) feed on dead skin and parasites on the surface of larger fish — the cleaner fish get a meal and the larger fish are helped to stay healthy.

Parasitism

Parasitism is another example of interdependence. Parasites live very closely with a host species (e.g. in or on them). The parasite takes what it needs to survive, but the host doesn't benefit.

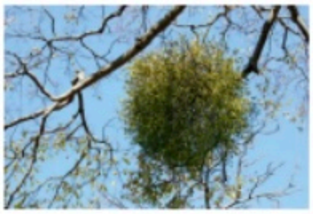


Figure 4: Mistletoe (dense green ball) growing on the branches of a tree.

Examples

- Fleas are parasites of mammals such as dogs. Fleas feed on their host's blood, but don't offer anything in return.
- The plant mistletoe is a parasite. It grows on the branches of trees (see Figure 4) such as apple and hawthorn, and depends on them for water and mineral ions. The trees themselves don't benefit and can be killed if too much mistletoe grows on them (especially during dry weather, when there's not enough water to be shared).

Practice Questions — Fact Recall

Q1 What's the difference between a population of organisms and a community of organisms?

Q2 What is the smallest level of organisation in an ecosystem?

Practice Questions — Application

Q1 Which of the following is an example of an ecosystem?

A The water in a stream.

B The trout that live in a stream.

C All the fish, insects, aquatic mammals, birds and amphibians that live in a stream.

D All the fish, insects, aquatic mammals, birds and amphibians that live in a stream, along with factors such as the pH, temperature and oxygen content of the water.

Q2 Spider crabs live on the sea bed. Algae grow on the crabs' backs, making the crabs blend in with their surroundings. The algae make their own food through photosynthesis and don't take anything from the crabs. Is this an example of a mutualistic or a parasitic relationship? Explain your answer.

2. Abiotic and Biotic Factors

Ecosystems contain abiotic (non-living) and biotic (living) factors.

Learning Objective:

- Be able to explain how communities can be affected by abiotic and biotic factors, including:
  - temperature, light, water and pollutants;
  - competition and predation.

Specification Reference 9.2

Changes in ecosystems

Ecosystems change all the time. These changes are caused by both abiotic and biotic factors and they affect communities in different ways. For example, a change might cause the population size of one species to increase and the population size of another species to decrease. Alternatively, the distribution of populations (where they live) may change.

Abiotic factors

Some changes to ecosystems are caused by abiotic factors. These include things like temperature, light intensity, the availability of water or the presence of pollutants. They can all affect communities in different ways:

Examples

- Temperature — the distribution of some bird species is probably changing because of a rise in average temperature. For instance, the European bee-eater bird is a Mediterranean species but it's now present in parts of Germany.
- Light intensity — as trees grow and develop more branches, the ground below them becomes more shaded. This might stop grasses from growing underneath the trees because grasses need plenty of light to grow. The grasses may be replaced by fungi (or mosses, etc.) which are better able to cope with the lower light intensity.
- Amount of water — all organisms need water to live, so a change in the availability of water usually has a big effect on communities. E.g. daisies grow best in soils that are slightly damp. If the soil becomes waterlogged or too dry, the population of daisies in that area will decrease.
- Levels of pollutants — lichens are unable to survive if the concentration of sulfur dioxide (an air pollutant) is too high (see p.308). So an increase in sulfur dioxide concentration might reduce the population size of the lichens in an area.

Tip: Plants need light for photosynthesis (see page 198). Most plants need lots of light but some are adapted to living in areas of low light intensity.

Tip: Animals and fungi don't photosynthesise, so they don't need light to grow. This means they're not usually directly affected by changes to light intensity.

Biotic factors

Biotic factors also change ecosystems. Biotic factors relate to living organisms, so they include things like competition and predation.

Competition

Organisms need things from their environment and from other organisms in order to survive and reproduce. Plants need light and space, as well as water and mineral ions (nutrients) from the soil. Animals need space (territory), food, water and mates. Organisms compete with other species (and members of their own species) for the same resources.

Examples

- Weeds compete with crop plants for light and nutrients. Farmers use weedkillers to kill weeds so there is less competition and the crops get all the light and nutrients, which enables them to grow better.
- Lions and hyenas share the same habitat in Africa. They compete with each other for food, water and territory, which results in frequent aggression between the two species.
- Male peacocks compete with each other for mates by displaying their eye-catching tail feathers to females during mating season.

Predation

Tip: Disease (caused by pathogens) is another biotic factor that affects communities.

Animals that hunt and kill other animals are called predators, and the animals they eat are called prey. In a community containing prey and predators (as most of them do), the population of any species is usually limited by the amount of food available. If the population of the prey increases, then so will the population of the predators. However as the population of predators increases, the number of prey will decrease.

Example

Lions are predators. They have a number of different prey species, including gazelles. An increase in the number of gazelles might lead to an increase in the number of lions, because there'll be more food for the lions to eat. However, the increase in the number of lions might in turn lead to a decrease in the number of gazelles, as more of them will be eaten by lions.

Practice Questions — Fact Recall

Q1 Give three examples of abiotic factors.

Q2 Give two examples of biotic factors.

Practice Question — Application

Q1 An environmental study was done on a lake over a number of years. Over the course of the study, the concentration of oxygen in the lake gradually decreased due to the effect of pollution. A certain species of fish found in the lake cannot survive in water with a low oxygen concentration. Herons feed on these fish.

a) The population size of the fish changed during the study.

i) Suggest how the population size changed.

ii) Was this change due to a biotic or abiotic factor?

b) The population size of the herons also changed during the study. Suggest how and why the population size changed.

3. Investigating Ecosystems

CORE PRACTICAL

You don't just need to learn the facts about ecosystems — you need to be able to investigate them too.

Distribution of organisms

You might remember from page 280, that an ecosystem is a community of organisms, along with all the abiotic parts of their environment. The distribution of an organism is where that organism is found, either in the whole ecosystem or a particular part. The abiotic factors in an ecosystem affect the distribution of the organisms that live there.

Examples

- In a field ecosystem, you might find that daisies are more common in the open than under trees, because there's more light available in the open and daisies need light to survive (they use it for photosynthesis — see p.198).
- Some types of mayfly are more common in colder parts of a stream, as they can't tolerate the warmer temperatures in other parts of the stream.

There are a couple of ways to study the distribution of an organism:

1. You can measure how common an organism is in two or more sample areas (e.g. using **quadrats** — see below) and compare them.
2. You can study how the distribution changes across an area, e.g. by placing quadrats along a **transect** (see pages 286-287).

Both of these methods give quantitative data (numbers) about the distribution.

Quadrats

A quadrat is a square frame enclosing a known area, e.g. 1 m² (see Figure 1).

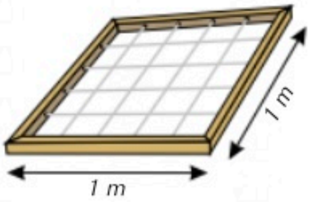


Figure 1: *A diagram of a 1 m² quadrat.*

Investigating distribution

You can use quadrats to study the distribution of small organisms that are slow moving or that don't move around. You can investigate the effect of a factor on the distribution of a species by comparing how common an organism is in two sample areas (e.g. shady and sunny spots in a playing field). Just follow these simple steps:

1. Place a 1 m² quadrat on the ground at a random point within the first sample area. E.g. divide the area into a grid and use a random number generator to pick coordinates (see page 321).
2. Count all the organisms that you're interested in within the quadrat.
3. Repeat steps 1 and 2 as many times as you can.
4. Work out the mean number of organisms per quadrat within the first sample area.

Learning Objectives:

- Be able to investigate the relationship between organisms and their environment using field-work techniques, including quadrats and belt transects. (Core Practical)
- Be able to explain how to determine the number of organisms in a given area using raw data from field-work techniques, including quadrats and belt transects.

Specification References
9.5, 9.6

Tip: You might not be in the lab, but fieldwork still has hazards. Make sure you do a full risk assessment before you start investigating any ecosystem.

Tip: It's really important that the quadrats are placed randomly within the sample area. Taking random samples will make sure the results you get are representative of the whole sample area. This improves the validity of the study.

WORKING SCIENTIFICALLY

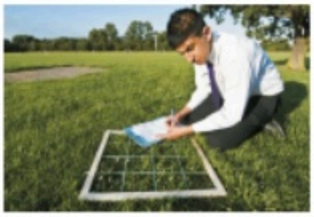


Figure 2: *A student using a quadrat to gather data on the distribution of organisms.*

Example

Anna counted the number of daisies in 7 quadrats within her first sample area and recorded the following results:

Quadrat	1	2	3	4	5	6	7
Number of Daisies	18	22	20	23	23	25	23

Here the mean is: $\frac{\text{total number of organisms}}{\text{number of quadrats}} = \frac{154}{7} =$ **22 daisies per quadrat**

Tip: If you're counting flowering plants in your quadrat, make sure you count the number of actual plants, not the number of flowers. Some plants will have more than one flower, and some might not currently have any flowers on them.

5. Repeat steps 1 to 4 in the second sample area.
6. Finally compare the two means. E.g. you might find 2 daisies per m^2 in the shade, and 22 daisies per m^2 (lots more) in the open field.

You might want to find and compare the mode and median of your data too.

Tip: There's more on different types of averages on p.14.

Example

1. The mode is the number that appears most often in the data. For Anna's data above, the mode is **23 daisies per quadrat**.
2. To find the median, you first need to put your data in numerical order. The median is the middle value in your data.

   18, 20, 22, 23, 23, 23, 25

   The median of Anna's data is **23 daisies per quadrat**.

Estimating population size

You can also use quadrats to work out the population size of an organism in one area.

Example

Students used a quadrat with an area of 0.25 m^2 to randomly sample daisies in an open field. The students found a mean of 10.5 daisies per quadrat. The field had an area of 800 m^2. Estimate the population of daisies in the field.

1. Work out the mean number of organisms per m^2.

   $1 \div 0.25 = 4$ ← *Because the quadrat is only 0.25 m^2, first you need to work out how many quadrats make up 1 m^2.*

   $4 \times 10.5 = 42$ daisies per m^2

2. Then multiply the mean by the total area (in m^2) of the habitat.

   $42 \times 800 =$ **33 600 daisies in the open field**

Tip: If your quadrat has an area of 1 m^2, the mean number of organisms per m^2 is just the same as the mean number per quadrat.

Transects

Sometimes abiotic factors change gradually across a habitat. This change is known as an **environmental gradient**. You can use lines called transects (see Figure 3 on the next page) to help find out how organisms (like plants) are distributed along a gradient — for example, if a species becomes more or less common as you move from an area of shade (near a hedge at the edge of a field) towards an area of full sun (in the middle of the field).

Tip: Transects can be used in any type of habitat, not just fields. For example, along a beach or in a stream.

There are different types of transects. A **belt transect** is where quadrats are laid out along the line. You need to know how to collect data along a belt transect.

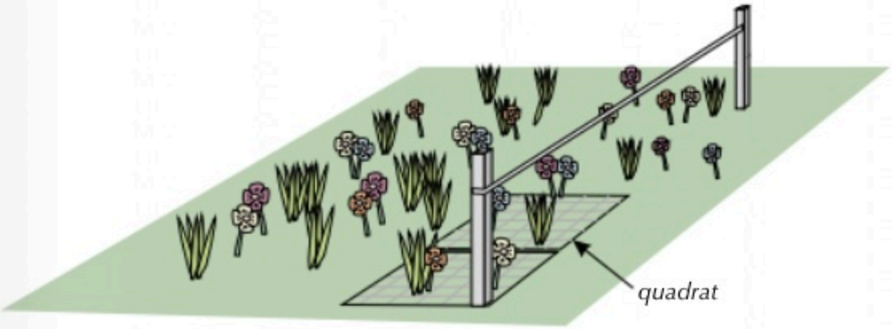


Figure 3: *A diagram showing a belt transect.*

Figure 4: *Students using a quadrat along a transect.*

Here's what to do:

1. Mark out a line in the area you want to study using a tape measure, for example from the hedge to the middle of the field.
2. Then collect data along the line using quadrats placed next to each other. If your transect is quite long, you could place the quadrats at regular intervals (e.g. every 2 metres) instead.
3. Collect data by counting all the organisms of the species you're interested in, or by estimating percentage cover. This means estimating the percentage area of a quadrat covered by a particular type of organism.
4. You could also record other data, such as the abiotic factors in each quadrat (e.g. you could use a light meter to measure the light intensity).
5. Repeat steps 1 to 4 several times, then find the mean number of organisms (or mean percentage cover) for each quadrat and a mean value for the abiotic factor you measured at each quadrat.

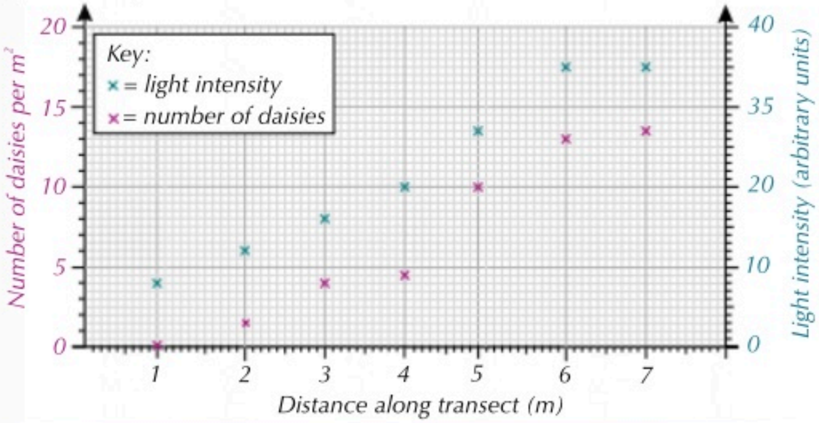
Tip: If you've got a long transect, placing quadrats at intervals will be quicker.

Tip: If your quadrat is divided up into smaller squares, you can estimate the percentage cover of an organism by counting the number of squares more than half covered by that organism. E.g. if 55 out of 100 squares are more than half covered by grass, the percentage coverage of the grass is 55%. This is a useful technique when individual organisms are hard to count.

Once you've collected your data, you could use it to plot graphs. This could help you to see if the changing abiotic factor is correlated with a change in the distribution of the species you're studying.

Example

The graph below shows the data collected along a belt transect. You can see that the number of daisies and the light intensity at each distance are positively correlated (see p.18) — as the light intensity increases, so does the number of daisies.



Tip: Make sure you can correctly identify the organisms you are investigating. If necessary, use books or information from the internet to help you.

Tip: There's more on drawing graphs on pages 16-18.

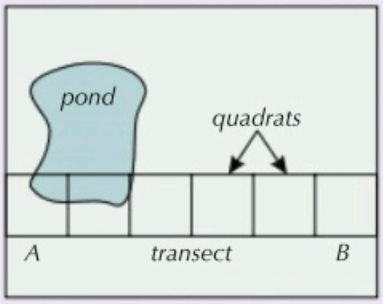
Practice Questions — Fact Recall

Q1 Describe how you would use random sampling with a quadrat to compare the distribution of organisms in two sample areas.

Q2 Describe how you would use a belt transect to measure the distribution of organisms across an area.

Practice Questions — Application

Q1 Joanne read that bulrushes grow best in moist soil or in shallow water. She wanted to find out whether this is true, so she investigated the distribution of bulrushes in her garden. She used a transect (as shown in the diagram) and recorded the number of bulrushes in each 1 m^2 quadrat as shown in the table.



Quadrat	1	2	3	4	5	6
Number of Bulrushes	1	5	5	20	43	37

a) Calculate the mean number of bulrushes per quadrat.

b) Joanne started counting at quadrat 1 and moved along the transect in order, to quadrat 6. Assuming that the information Joanne read was correct, do you think quadrat 1 is at end A or end B of the transect? Explain your answer.

Q2 An area of the Lake District was sampled for the presence of a species of slug. Conservationists used quadrats, each with an area of 0.25 m^2, placed randomly in the landscape. The mean number of the slugs found in a quadrat was 2.5 and the area under investigation was 2000 m^2.

Estimate the total population of the slugs in the area.

4. Ecosystems and Energy Transfers

There's a lot of energy moving around in ecosystems.
Energy gets transferred through food chains.

Learning Objective:

- Be able to explain how some energy is transferred to less useful forms at each trophic level and that this affects the number of organisms at each trophic level, limits the length of a food chain and determines the shape of a pyramid of biomass in an ecosystem.

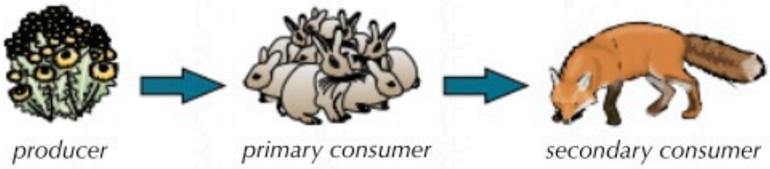
Specification Reference 9.7B

Food chains

Food chains show what's eaten by what in an ecosystem. Food chains always start with a **producer** — usually a green plant or alga. Producers make (produce) their own food using energy from the Sun (which is the source of energy for nearly all life on Earth).

Producers are eaten by **primary consumers**. Primary consumers are then eaten by **secondary consumers** and secondary consumers are eaten by **tertiary consumers**. Each stage of a food chain is called a **trophic level**.

Example



100 dandelions... feed... 10 rabbits... which feed... one fox

Tip: The arrows in a food chain show you the direction of energy transfer, e.g. energy is transferred from the producer to the primary consumer. Remember, you can imagine that the arrows mean 'is eaten by'.

Energy transfer in food chains

Producers use photosynthesis (see page 198) to convert a small percentage of the light energy that falls on them into glucose. They use some of the glucose immediately in respiration and store some of the rest as **biomass** (the mass of living material that makes up an organism).

When a primary consumer eats a producer, it uses some of the energy it gets from the producer (e.g. in respiration, see below) and some of the rest is stored in its body as biomass. A secondary consumer then eats the primary consumer and gets some of the energy stored in the primary consumer's biomass.

Tip: There's more on respiration on pages 270-272.

So energy is transferred through food chains when organisms eat other organisms. However, not much energy gets transferred from one trophic level to the next. In fact, only about 10% of the energy is passed on to the next level — the rest is 'lost' to the food chain.

How is energy lost from food chains?

At each trophic level, organisms need to respire in order to transfer energy for life processes (e.g. movement). A lot of this energy ends up transferred to the surroundings by heat. This energy isn't stored as biomass, so it isn't transferred to the organisms in the next trophic level.

Tip: The energy that's 'lost' doesn't disappear. It's just transferred out of the food chain, so it's not available to organisms in the next trophic level up.

Energy that does get stored as biomass doesn't all get transferred to the next trophic level either. That's because not all of an organism gets eaten (e.g. bones) and because not all of the bits that do get eaten can be digested. Undigested material is lost from the food chain in faeces.

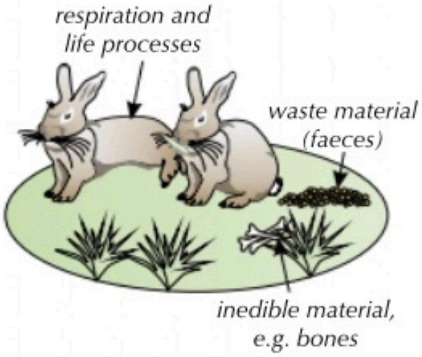


***Figure 1:** Diagram summarising the ways in which energy is lost at each stage in a food chain.*

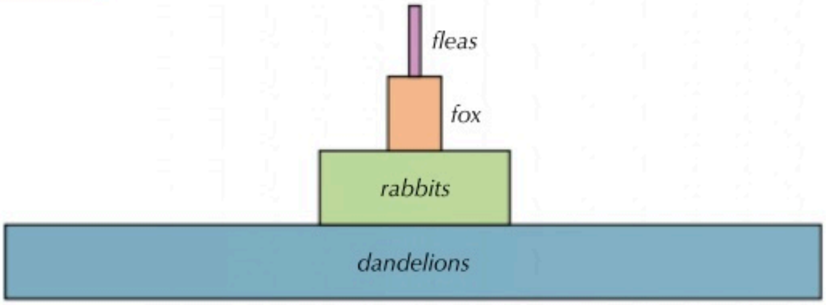
This explains why you hardly ever get food chains with more than about five trophic levels. So much energy is lost at each stage that there's not enough left to support more organisms after four or five stages. You also tend to get fewer organisms at each trophic level (although this isn't always the case).

Pyramids of biomass

A pyramid of biomass shows the relative mass of organisms at each trophic level in a food chain. Every time you go up one trophic level in a food chain, the mass of organisms goes down. This is because most of the energy is lost and so does not get stored as biomass in the next level up. This gives rise to the pyramid shape that almost every pyramid of biomass has.

Tip: Since biomass is a store of energy (see previous page), a pyramid of biomass also shows the relative amount of energy at each trophic level.

Example



Tip: If you weighed all the organisms in this example, the dandelions would have a very big biomass and the fleas would have a very small biomass.

Tip: In this example, there are lots of fleas and only one fox, but the biomass is still decreasing even though the number of organisms isn't. That's because lots of fleas weigh less than one fox.

The big bar along the bottom of the pyramid shows trophic level 1. It always represents the producer. The next bar will be the primary consumer, then the secondary consumer and so on up the food chain.

Constructing a pyramid of biomass

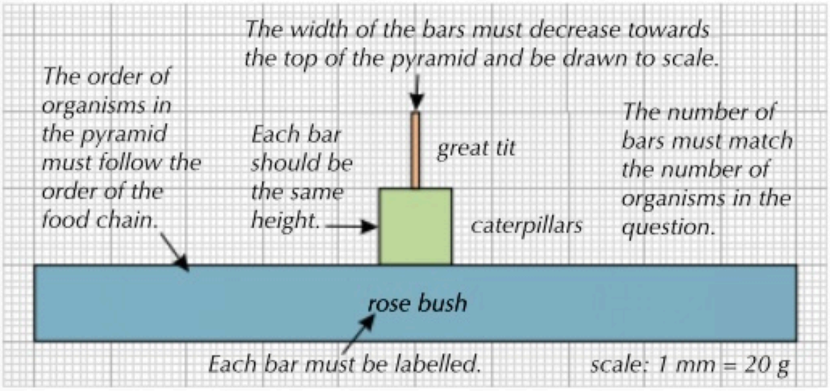
You need to be able to construct pyramids of biomass. Luckily it's pretty simple — they'll give you all the information you need to do it in the exam.

Example

A great tit weighing 20 g feeds on caterpillars weighing 190 g in total, which in turn feed on a rose bush weighing 2000 g. Draw and label a pyramid of biomass to represent this food chain.

In a pyramid of biomass, the width of each bar represents the biomass of the organisms present at that level.

Here's what you need to remember when drawing a pyramid of biomass:


The width of the bars must decrease towards the top of the pyramid and be drawn to scale.
The order of organisms in the pyramid must follow the order of the food chain.
Each bar should be the same height.
great tit
caterpillars
The number of bars must match the number of organisms in the question.
rose bush
Each bar must be labelled.
scale: 1 mm = 20 g

Practice Questions — Fact Recall

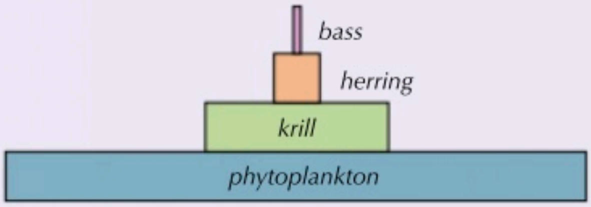
Q1 How is energy transferred through food chains?

Q2 Give two ways in which energy can be lost from food chains.

Q3 What limits the number of trophic levels in a food chain?

Practice Question — Application

Q1 Look at this pyramid of biomass.


bass
herring
krill
phytoplankton

a) Which organism is the producer?

b) Which organism has the smallest biomass?

c) Why is the bar representing the herring smaller than the bar representing the krill?

Exam Tip

If you're asked to draw a pyramid of biomass from scratch, you'll need to decide on a suitable scale for the bars. Whatever scale you pick, the largest bar needs to fit in the space you're provided with. In this example, each small square on the graph paper is 1 mm wide. The largest bar is 100 mm wide, so each mm represents 20 g. All of your bars have to use the same scale.

Exam Tip

Make sure that any pyramids of biomass you draw in exams take up at least two thirds of the space you've been provided with.

5. Calculating Energy Transfers

It's time to put some numbers to those energy transfers...

Learning Objective:

- Be able to calculate the efficiency of energy transfers between trophic levels and carry out percentage calculations of biomass.

Specification Reference 9.8B

How do I calculate energy transfers?

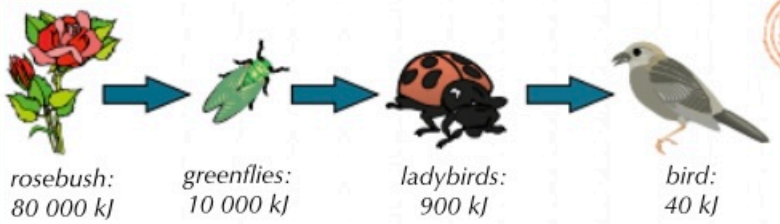
You can work out how much energy has been lost at each trophic level in a food chain by taking away the energy that is transferred to the next level from the energy that was available at the previous level.

You can also calculate the efficiency of energy transfer between trophic levels using this formula:

$$\text{efficiency} = \frac{\text{energy transferred to the next level}}{\text{energy available at the previous level}} \times 100$$

Exam Tip
Always double check that you're using the formula the right way round, otherwise you could be chucking away relatively easy marks.

Example



Tip: kJ is a unit of energy.

The numbers show the amount of energy available to the next level. So 80 000 kJ is the amount of energy available to the greenflies, and 10 000 kJ is the amount available to the ladybirds.

Energy lost between the first and second trophic levels:

= 80 000 kJ – 10 000 kJ

= **70 000 kJ**

Efficiency of energy transfer between the first and second trophic levels:

$$= \frac{10\,000}{80\,000} \times 100$$

= **12.5%**

Tip: Efficiency is usually pretty low (around 10%).

You can also calculate the biomass lost between trophic levels or the efficiency of biomass transfer using the formulae above — just substitute the word 'energy' for 'biomass'.

Practice Question — Application

Q1 The diagram shows the biomass at each level of a food chain.

Trophic level 1 *57 kg* → *Trophic level 2* *5.8 kg* → *Trophic level 3* *0.56 kg* → *Trophic level 4* *0.055 kg*

Calculate the efficiency of biomass transfer between the 3rd and 4th trophic levels.

6. Human Impacts on Biodiversity

Humans have a big effect on the Earth's ecosystems — sometimes that effect is positive, but more often than not, it's negative.

Learning Objectives:

- Be able to explain the positive and negative human interactions within ecosystems and their impacts on biodiversity, including: eutrophication, fish farming, and the introduction of non-indigenous species.
- Be able to explain the benefits of maintaining local and global biodiversity, including the impact of reforestation and the conservation of animal species.

Specification References
9.9, 9.10

What is biodiversity?

Biodiversity is the variety of living organisms in an ecosystem. The greater the biodiversity in an ecosystem, the healthier that ecosystem is.

Human interactions within ecosystems often affect biodiversity. Sometimes we have a positive impact — in other words, we increase the number and variety of living organisms in an area. This can be done through things like reforestation (see next page) or conservation schemes (see page 295). However, we often have a negative effect. Anything that reduces the number of living organisms in an ecosystem has a negative effect on biodiversity.

How do humans reduce biodiversity?

By causing eutrophication

Humans put nitrates onto fields as fertilisers (see p.307). If too much fertiliser is applied and it rains afterwards, nitrates easily find their way into rivers and lakes. The result is eutrophication (an excess of nutrients in water) which can lead to the death of many of the species present in the water, reducing the biodiversity of the habitat. This is what happens:

1. Fertilisers enter the water, adding excess nitrates (more than plants in the water can take in).
2. The excess nitrates cause algae to grow fast and block out the light.
3. Plants can't photosynthesise due to lack of light and start to die and decompose. With more food available, microorganisms that feed on decomposing plants increase in number and use up oxygen in the water.
4. Organisms that need oxygen for aerobic respiration (e.g. fish) die.

These steps are illustrated in Figure 1.

Tip: Pollution by sewage can cause eutrophication in the same way that fertilisers do — by adding excess nitrates to the water.

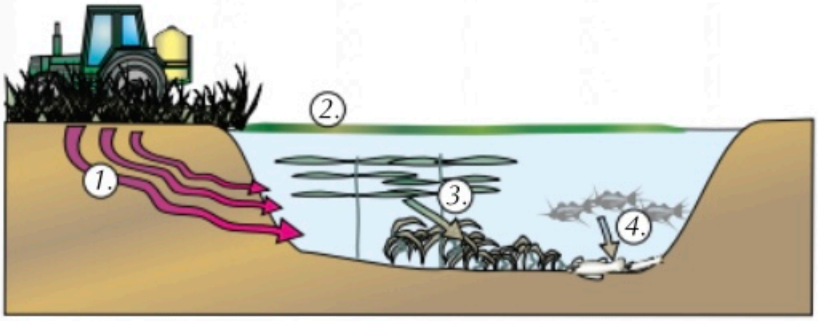


Figure 1: *Diagram to show how eutrophication occurs.*

Figure 2: *Water covered by an algal 'bloom' (a sudden increase in the amount of algae).*

Through fish farming

Fish can be farmed in holding nets in open water (e.g. lakes or the sea) — see Figure 3 on the next page. These farms can reduce biodiversity in the surrounding area. There are several different reasons for this.

One reason is that food is added to the nets to feed the fish, and the fish produce huge amounts of waste. Both the food and the waste can leak into the open water, causing eutrophication and the death of wild species.

Fish farms in open water also often act as a breeding ground for large numbers of parasites. These parasites can get out of the farm and infect wild animals, sometimes killing them. Predators (e.g. sea lions) are attracted to the nets and can become trapped in them and die. Finally, farmed fish sometimes escape into the wild, causing problems for wild populations of indigenous species (see below).

Fish can also be farmed in large tanks rather than in open water nets. These farms are low in biodiversity because often only one species is farmed, the tanks are often kept free of plants and predators, and any parasites and microorganisms are usually killed.

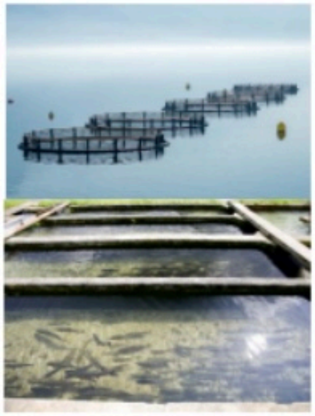


Figure 3: *Fish being farmed in open water nets (top) and fish being farmed in tanks (bottom).*

Tip: Non-indigenous species are sometimes introduced as a method of biological pest control (see page 148).

Through the introduction of non-indigenous species

A non-indigenous species is one that doesn't naturally occur in an area. They can be introduced intentionally (e.g. for food or hunting) or unintentionally (e.g. as a stowaway in international cargo). The introduction of a non-indigenous species may cause problems for indigenous (native) species.

Non-indigenous species compete with indigenous species for resources like food and shelter. Sometimes, they are better at getting these resources and out-compete the indigenous species, which decrease in number and eventually die out. Non-indigenous species sometimes also bring new diseases to a habitat. These often infect and kill lots of indigenous species, reducing the habitat's biodiversity.

Example

Signal crayfish were introduced to the UK for food, but they prey on and out-compete many indigenous river species, reducing biodiversity. They also carry a disease that kills indigenous crayfish.

Figure 4: *An American signal crayfish.*

How can humans maintain biodiversity?

While lots of human activities reduce biodiversity, there are plenty of things that we can do to increase biodiversity or help to maintain it.

Reforestation

Reforestation is when land where a forest previously stood is replanted to form a new forest (or a new forest is allowed to regrow naturally). Forests generally have a high biodiversity because they contain a wide variety of trees and plants, and these provide food and shelter for lots of different animal species. Deforestation reduces this biodiversity by removing the trees (either by chopping them down or burning them). Reforestation helps to restore it.

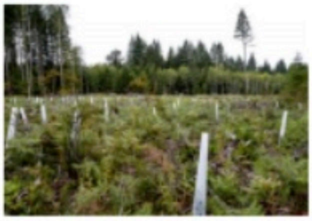


Figure 5: *Seedlings (in plastic protective sleeves) planted to reforest an area cleared by logging.*

Reforestation programmes need to be carefully planned to maximise positive effects and minimise negative ones. For example, replanting a forest with a variety of tree species will result in a higher biodiversity than replanting using only a single type of tree.

Conservation schemes

Conservation schemes can help to protect biodiversity by preventing species from dying out. Conservation methods include protecting a species' natural habitat (so that individuals have a place to live) and protecting species in safe areas outside of their natural habitat. Captive breeding programmes can be introduced in safe areas to increase numbers.

Tip: Zoos can be used as safe areas for the protection of animals. Some zoos run captive breeding programmes.

Tip: Seed banks can also be used to store and distribute the seeds of rare and endangered plants.

The benefits of maintaining biodiversity

There are lots of benefits to both wildlife and humans of maintaining biodiversity on a local and global scale.

Examples

- Protecting the human food supply — e.g. over-fishing has greatly reduced fish stocks in the world's oceans. Conservation programmes can ensure that future generations will have fish to eat.
- Ensuring minimal damage to food chains — if one species becomes extinct it will affect all the organisms that feed on and are eaten by that species, so the whole food chain is affected. This means conserving one species may help others to survive.
- Providing future medicines — many of the medicines we use today come from plants. Undiscovered plant species may contain new medicinal chemicals. If these plants are allowed to become extinct, e.g. through rainforest destruction, we could miss out on valuable medicines.
- Cultural aspects — individual species may be important in a nation's or an area's cultural heritage, e.g. the bald eagle is being conserved in the USA as it is regarded as a national symbol.
- Ecotourism — people are drawn to visit beautiful, unspoilt landscapes with a variety of animal and plant species. Ecotourism (environmentally-friendly tourism) helps bring money into biodiverse areas where conservation work is taking place.
- Providing new jobs — things such as ecotourism, conservation schemes and reforestation schemes can provide employment for local people.

Practice Questions — Application

Q1 Thousands of years ago, huge areas of Scotland were covered in forests. Many of these forests have now been lost — some of this loss is due to deforestation by humans. Campaigns are underway to restore some of Scotland's lost forests.

a) Explain how reforestation could increase biodiversity in Scotland.

b) Suggest two benefits to humans of reforestation in Scotland.

Q2 A scientist carries out regular surveys to monitor the biodiversity along a stretch of river. The scientist finds that biodiversity is lower in the part of the river that runs through a farmer's wheat fields. Suggest and explain a reason for this.

Learning Objective:

- Be able to describe the biological factors affecting levels of food security, including:
  - an increasing human population,
  - increasing animal farming and increased meat and fish consumption,
  - environmental change caused by human activity,
  - sustainability issues, e.g. use of land for biofuel production and the cost of agricultural inputs,
  - the impact of new pests and pathogens.

Specification Reference 9.11B

7. Food Security

Humans and their activities don't just affect ecosystems...

The increasing human population

There are currently over seven billion people in the world — the population is rising very quickly, and it's not slowing down (see Figure 1).

This means that global food production must increase too, so that we all have access to enough food that is safe for us to eat and has the right balance of nutrition — this is known as **'food security'**. The increasing human population is a biological factor affecting food security. As the world's population continues to grow we need to produce more food, so that each person still has the same amount of food to eat.

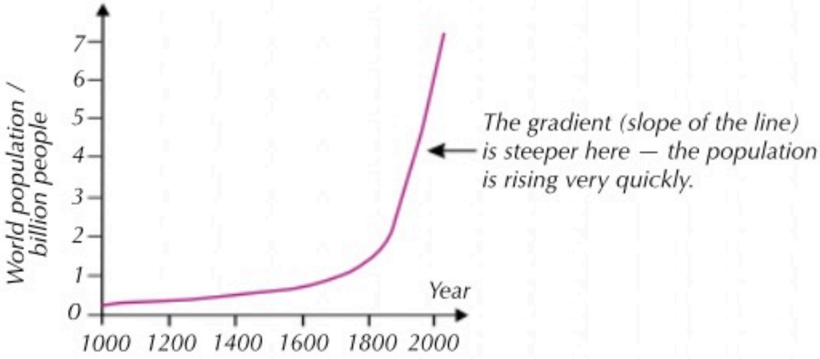


Figure 1: *Graph showing the increasing population of the world.*

Other biological factors affecting food security

The following biological factors also affect food security:

Increasing meat consumption and increasing animal farming

As people become wealthier, their diets are likely to change to include a wider variety of foods, including more meat and fish (which are expensive to buy). This can be bad news for food security.

There's less energy and less biomass every time you move up a stage in a food chain (see pages 289-290). So for a given area of land, you can produce a lot more food for humans by growing crops rather than by having grazing animals. Plus, animals and fish that are being reared to be eaten are often fed crops that would otherwise be eaten by humans (e.g. corn).

There's also a risk of over-fishing wild fish, so that there won't be enough available to catch in the future.

Environmental changes caused by human activity

Burning fossil fuels (coal, oil and natural gas) releases lots of carbon dioxide, which is a greenhouse gas. Greenhouse gases naturally trap energy in the atmosphere — this helps to keep the Earth warm. But increasing levels of greenhouse gases are causing the global temperature to rise. This is known as **global warming**. Global warming is a type of climate change and it causes other forms of climate change, e.g. changing rainfall patterns.

Climate change may affect the growth of crops, which could reduce yields. Other changes caused by humans, such as soil pollution, could also reduce our ability to grow crops.

Tip: The yield of a crop is the amount of food or other useful product produced.

A lack of sustainability

Sustainability means meeting the needs of today's population without affecting the ability of future generations to meet their needs. We must think about sustainability when addressing food security.

Examples

- Diesel and petrol are made from crude oil — a non-renewable fossil fuel that will eventually run out. There's currently an increase in the growth of crops to make biofuels, e.g. bioethanol, which is made by fermenting the sugar in corn and sugar cane. Biofuels are renewable alternatives to fossil fuels, but the crops grown to produce them take up land that could be used for food crops. We need to balance our need to grow crops for biofuels with the need to grow more food, now and in the future.
- The high input costs of farming (e.g. the price of fertilisers, fuel and machinery) may make it too expensive for farmers in some areas to continue farming and maintain food production in the future.

Tip: Renewable means that it won't run out — we can grow more crops to make more biofuels.

New pests and pathogens

Pests (e.g. some insects) and pathogens (e.g. bacteria, fungi) can cause damage to crops and livestock.

When new pests and pathogens emerge, they can have a negative impact on yields. E.g. if a new disease spreads to a crop, lots of the population may not be resistant to the disease. This means a large number of the crop plants will be damaged, reducing the yield and the amount that can be sold as food.

Practice Questions — Fact Recall

Q1 Why does the increasing human population affect food security?

Q2 Explain how increasing meat consumption may affect food security.

Q3 Describe one sustainability issue that needs to be considered when addressing food security.

Topic 9a Checklist — Make sure you know...

Ecosystems and Interactions Between Organisms

☐ That ecosystems are organised into different levels — from individual organisms to populations (all the organisms of one species) to communities (all the organisms of different species) to the ecosystem itself (the community of organisms, plus all of the abiotic conditions).

☐ That organisms depend on each other for survival and that this is known as interdependence.

☐ That mutualism (an example of interdependence) is a relationship between two organisms, where both organisms benefit.

cont...

☐ That parasitism (also an example of interdependence) is a relationship between two organisms, where one organism (the parasite) takes what it needs to survive but the other organism (the host) doesn't benefit.

Abiotic and Biotic Factors

☐ How communities can be affected by abiotic (non-living) factors, including temperature, light intensity, availability of water and the level of pollution.

☐ How communities can be affected by biotic (living) factors, such as competition and predation.

Investigating Ecosystems

☐ How to use quadrats and belt transects to investigate how abiotic factors affect the population sizes or distribution of organisms in an ecosystem. (Core Practical)

☐ How to determine the number of organisms in an area using data from quadrats and belt transects.

Ecosystems and Energy Transfers

☐ That some energy is transferred to less useful forms (e.g. through respiration) at each trophic level in a food chain. How this limits the number of levels in a food chain, sometimes limits the number of organisms at each trophic level and determines the shape of a pyramid of biomass.

Calculating Energy Transfers

☐ How to calculate the efficiency of energy or biomass transfers in a food chain, using the formula: energy (or biomass) transferred to next level ÷ energy (or biomass) available at previous level × 100.

Human Impacts on Biodiversity

☐ That biodiversity is the variety of living organisms in an area.

☐ How humans can negatively impact biodiversity in ecosystems through: eutrophication (an excess of nutrients in water leading to increased algal growth and the death of other organisms in the water), fish farming and the introduction of non-indigenous species to an area.

☐ How humans can positively impact biodiversity through reforestation and conservation schemes.

☐ Some of the benefits of maintaining biodiversity in an area.

Food Security

☐ That food security is having access to enough food that is safe and has the right balance of nutrition.

☐ That the increasing human population is threatening food security, and that we need to grow more food so that people have enough to eat.

☐ How these things affect food security: increasing meat and fish consumption, increasing animal farming, environmental changes caused by human activities, sustainability issues (including growing crops to produce biofuels and the costs of agricultural inputs) and new pests and pathogens.

Exam-style Questions

1 A biology class were studying the distribution of organisms on a rocky shore line. Three students each set up a transect which ran from the water's edge up the shore, as shown in **Figure 1**. All three students counted the number of limpets in each of the 50 cm × 50 cm quadrats. The number of limpets counted by each student are shown in **Figure 2**.

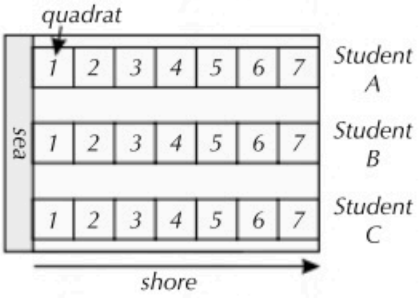


Figure 1

Quadrat number	1	2	3	4	5	6	7
Student A No. of Limpets	18	65	70	55	30	10	0
Student B No. of Limpets	6	72	76	41	21	18	3
Student C No. of Limpets	14	83	84	57	26	16	1

Figure 2

(a) Calculate the mean number of limpets found in quadrat 4.

(2 marks)

(b) Limpets need to stay moist in order to survive, but they are able to survive for a period of time without water by clamping down onto the surface of rocks — this helps to prevent them from drying out. Close to the water's edge, limpets have lots of competition from other species for space.

Use this information and the data in **Figure 2** to describe the distribution of limpets along the shore line and suggest reasons for it.

(3 marks)

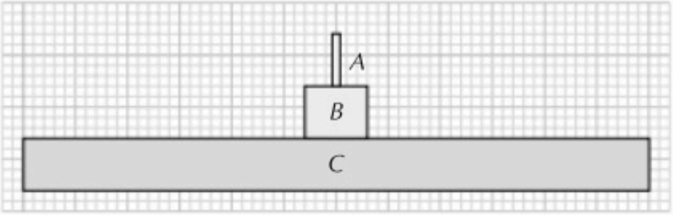
(c) During the class study, another group of students investigated the distribution of a type of starfish. They placed 20 quadrats at random in each sample area of shoreline that they were interested in studying.

Explain why the students placed their quadrats randomly.

(2 marks)

2 **Figure 3** shows a pyramid of biomass.
It represents a food chain involving algae, fish and birds.

Figure 3



(a) Which bar on the pyramid (A, B or C) represents the algae? Explain your answer.

(1 mark)

(b) Calculate the ratio of bar C to bar B.

(2 marks)

(c) Neither of the ratios in the pyramid of biomass (bar C to bar B, or bar B to bar A) are 1:1 because biomass and energy are lost as you go up a food chain. Explain how energy is lost from a food chain.

(3 marks)

(d) Explain why the Sun is needed at the start of all food chains.

(4 marks)

3 Scientists have been studying a species of wolf. The wolf lives in rocky mountains where the temperature at night can drop as low as –15 °C. The wolf has adaptations such as thick fur, which allow it to survive in this environment. Its main source of prey is rodents that live in burrows beneath the ground.

Scientists have been recording the total population size of the wolf over a number of years. Their findings and some other data are shown in **Figure 4**.

(a) Describe the overall trend in the total population size of the wolf species studied.

(1 mark)

(b) Suggest the biotic factor that's responsible for this trend. Use data from the table to support your answer.

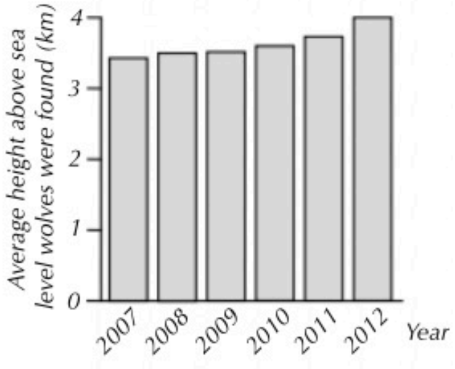
(3 marks)

Year	Total population size of wolf	Total population size of one type of prey (million)	Rabies outbreak in this year
2007	401	1.96	No
2008	327	2.01	Yes
2009	330	2.09	No
2010	341	2.06	No
2011	265	2.01	Yes
2012	269	1.99	No

Figure 4

(c) **Figure 5** shows the average height above sea level where the wolves are found.

Figure 5



Since 2007, the average temperature at 3.5 km above sea level has been increasing. Use data from **Figure 5** to suggest how this has affected the distribution of the wolf population.

(2 marks)

1. The Carbon Cycle

Materials such as carbon are being constantly recycled on Earth. It's really important that this happens. For example, it means that there's always enough material to make new organisms when old organisms die.

Learning Objectives:

- Be able to describe how different materials cycle through the biotic and abiotic components of an ecosystem.
- Be able to explain the importance of the carbon cycle, including the processes involved and the role of microorganisms as decomposers.

Specification References 9.12, 9.13

Recycling of materials

You might remember from page 280 that an ecosystem is all of the organisms living in an area, as well as all of the non-living conditions, e.g. soil type, availability of water and temperature. Materials are constantly recycled through both the living (biotic) and non-living (abiotic) components of ecosystems.

Living things are made of elements they take from the environment, e.g. plants take in carbon and oxygen from the air and nitrogen from the soil. They turn these elements into the complex compounds (carbohydrates, proteins and fats) that make up living organisms. Elements are passed along food chains when animals eat the plants and each other.

When waste products and dead organisms are broken down by decomposers (usually microorganisms such as bacteria and fungi) the elements in them are returned to the soil or air, ready to be taken in by new plants and put back into the food chain — the elements are recycled.

Tip: Decomposition of materials means that habitats can be maintained for the organisms that live there, e.g. nutrients are returned to the soil, and waste material (such as dead leaves) doesn't just pile up. There's more on decomposition on pages 310-312.

The carbon cycle

All living things contain carbon — so it's a pretty important element. However, there's only a fixed amount of carbon in the world. This means that carbon is constantly being cycled — from the air, through food chains and eventually back out into the air again. The carbon cycle shows how carbon is recycled — see Figure 1.

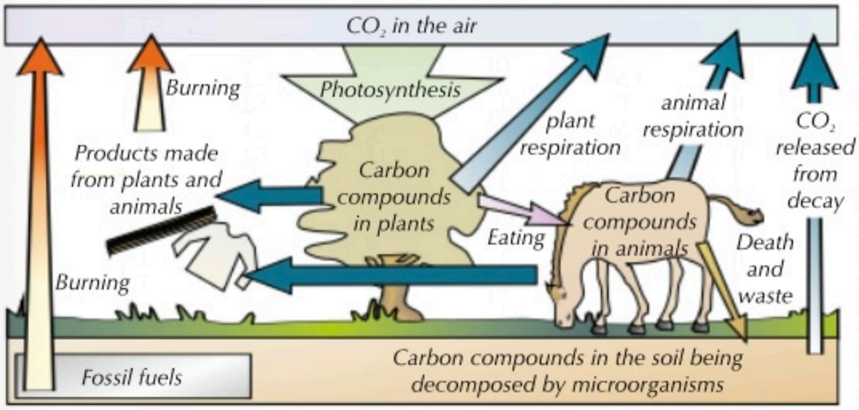

CO₂ in the air
Burning
Photosynthesis
plant respiration
animal respiration
CO₂ released from decay
Products made from plants and animals
Carbon compounds in plants
Carbon compounds in animals
Eating
Death and waste
Burning
Fossil fuels
Carbon compounds in the soil being decomposed by microorganisms

Figure 1: *Diagram showing the carbon cycle.*

Tip: Fossil fuels are made of decayed animal and plant matter.

Carbon is taken out of the air

The whole carbon cycle is "powered" by **photosynthesis**. CO_2 (carbon dioxide) is removed from the atmosphere by green plants and algae, and the carbon is used to make glucose, which can be turned into carbohydrates, fats and proteins that make up the bodies of the plants and algae.

Carbon moves through food chains

Some of the carbon becomes part of the fats and proteins in animals when the plants and algae are eaten. The carbon then moves through the food chain. The energy that green plants and algae get from photosynthesis is transferred up the food chain.

Tip: The term decomposers usually refers to microorganisms. However, 'detritus feeders' such as earthworms and woodlice are also decomposers.

Plants, algae and animals eventually die and **decompose** (they're broken down by microorganisms and other decomposers). Animals also produce waste, and this too is broken down by decomposers.

Carbon is returned to the air

Some carbon is returned to the atmosphere as CO_2 when the plants, algae and animals **respire**. It's returned to the atmosphere in the same way when decomposers such as microorganisms respire. CO_2 is also released back into the air when some useful plant and animal products, e.g. wood and fossil fuels, are burnt (combustion).

Tip: Respiration is the process of releasing energy from glucose. It also releases CO_2. There's more on respiration on pages 270-272.

Practice Questions — Fact Recall

Q1 How does CO_2 from the atmosphere first enter the food chain?

Q2 How does carbon move through food chains?

Q3 How is carbon returned to the atmosphere from dead leaves?

Practice Question — Application

Q1 The shells of many marine organisms are made from calcium carbonate (a compound containing calcium, carbon and oxygen). When these organisms die, their shells fall to the ocean floor and eventually form limestone rocks. The carbon inside the rocks returns to the atmosphere during volcanic eruptions or when the rocks are weathered down.

Explain how this example shows carbon moving between the abiotic and biotic parts of a marine ecosystem.

2. The Water Cycle

The water cycle is key to the survival of all living organisms. If it wasn't for the water cycle constantly recycling the water on Earth — we'd quickly run out of water to drink (and so would other animals and plants).

Learning Objective:

- Be able to explain the importance of the water cycle, including the processes involved and the production of potable water in areas of drought (including desalination).

Specification Reference 9.14

What is the water cycle?

The water here on planet Earth is constantly recycled. Energy from the Sun makes water **evaporate** from the land and sea, turning it into water vapour. Water also evaporates from plants — this is known as **transpiration** (see p.208). The warm water vapour is carried upwards (as warm air rises). When it gets higher up it cools and **condenses** to form clouds. Water falls from the clouds as **precipitation** (usually rain, but sometimes snow or hail) onto land, where it provides fresh water for plants and animals. Water not taken up by plants or animals drains into the sea, before the whole process starts again (see Figure 1).

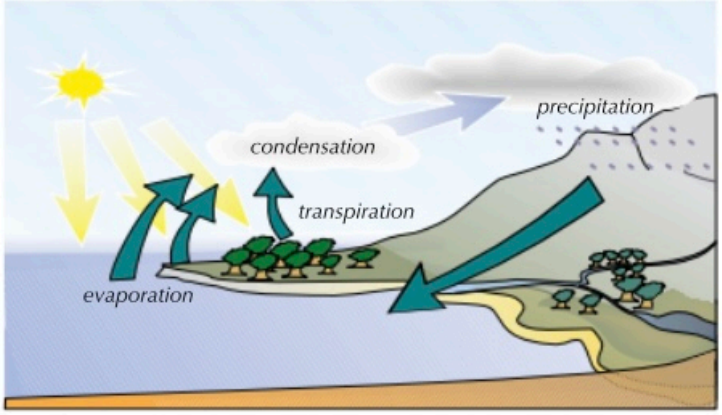


Figure 1: *Diagram showing the steps in the water cycle.*

Figure 2: *Rain (precipitation) is a key part of the water cycle, providing plants (and other organisms) with fresh water.*

The production of potable water

Potable water is water that's suitable for drinking. This means it must be clean and not too salty. In areas where there's a **drought** (in other words, there's not enough precipitation) it can be difficult to find potable water. That's partly because we rely on precipitation to get fresh water for drinking.

Luckily, in times of drought, there are methods we can use to produce potable water. One of these methods is called desalination.

Tip: Drinking salt water will make you sick.

Desalination

Desalination removes salts (mineral ions) from salt water (e.g. sea water). There are a few different methods of desalination.

Thermal desalination

Thermal desalination is very simple. Salt water is boiled in a large enclosed vessel, so that the water evaporates. The steam rises to the top of the vessel, but the salts stay at the bottom. The steam then travels down a pipe from the top of the vessel and condenses back into pure water — see Figure 3.

Tip: Thermal desalination is also known as distillation.

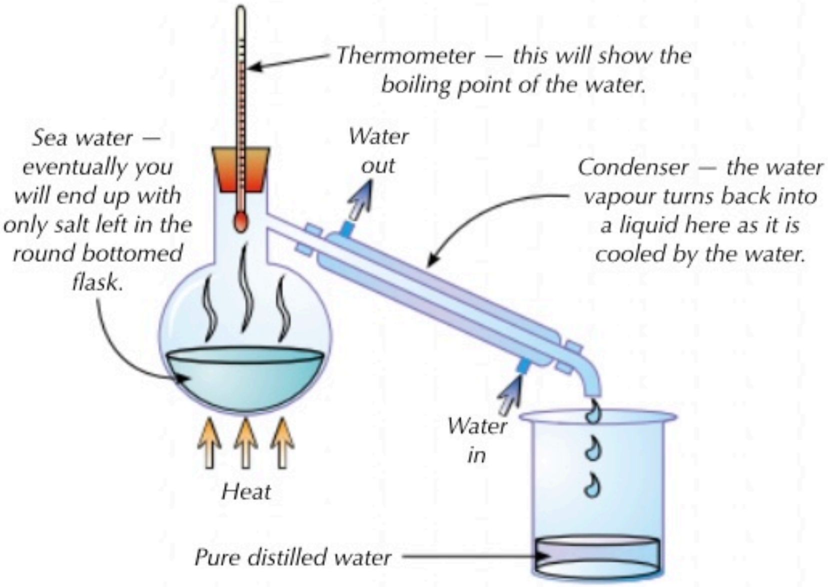

Thermometer — this will show the boiling point of the water.
Sea water — eventually you will end up with only salt left in the round bottomed flask.
Water out
Condenser — the water vapour turns back into a liquid here as it is cooled by the water.
Water in
Heat
Pure distilled water

Figure 3: *The thermal desalination of salt water.*

Reverse osmosis

Osmosis is the net movement of water across a partially permeable membrane, from an area of higher water concentration to an area of lower water concentration (see pages 49-50). The higher the salt concentration in a solution, the lower the water concentration, so you could also say that osmosis is the net movement of water from an area of lower salt concentration to an area of higher salt concentration. Reverse osmosis reverses this process to get rid of impurities in water. Here's how:

Tip: The partially permeable membrane allows water molecules through, but the large salts can't fit through the holes and are trapped.

1. Salt water is first treated to remove solids, before being fed at a very high pressure into a vessel containing a partially permeable membrane.
2. The pressure causes the water molecules to move in the opposite direction to osmosis — from a higher salt concentration to a lower salt concentration.
3. As the water is forced through the membrane, the salts are left behind, removing them from the water.

Figure 4: *An engineer inspecting reverse osmosis filters at a facility in Israel. The facility produces 127 million m^3 of fresh water from salt water per year.*

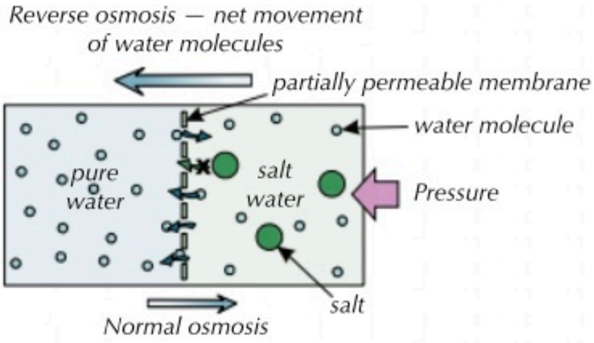

Reverse osmosis — net movement of water molecules
partially permeable membrane
water molecule
pure water
salt water
Pressure
salt
Normal osmosis

Figure 5: *Diagram to show how reverse osmosis works.*

Practice Questions — Fact Recall

Q1 How does water vapour in the atmosphere form clouds?

Q2 Name three types of precipitation.

Q3 What is potable water?

Q4 What is a drought?

Practice Questions — Application

Q1 A student said, "Some of the water in trees eventually ends up in the sea." Do you agree with this statement? Explain your answer.

Q2 The photograph below shows a desalination plant off the coast of a Greek island. During the summer months, the Greek islands are typically hot and sunny with very little rainfall. They are visited by thousands of tourists every year.

a) Suggest and explain why the Greek islands may benefit from desalination plants such as this.

b) The desalination plant has several solar panels. Suggest why these are needed.

Tip: A solar panel absorbs energy from the Sun. The energy can then be used for heating or to generate electricity.

3. The Nitrogen Cycle

Learning Objective:

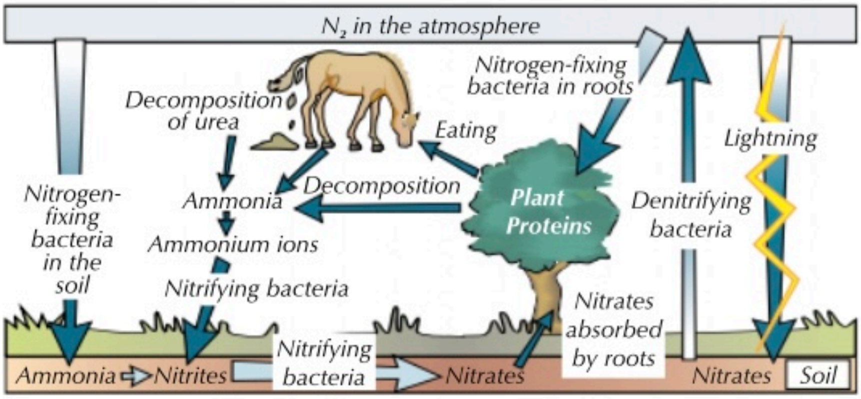
- Be able to explain how nitrates are made available for plant uptake, including the role of bacteria in the nitrogen cycle, crop rotation and the use of fertilisers.

Specification Reference 9.15

Like carbon and water, the nitrogen on Earth is constantly being recycled. Humans are able to influence this cycle for our own benefit.

The nitrogen cycle

The atmosphere contains 78% nitrogen gas, N_2. This is very unreactive and so it can't be used directly by plants or animals. Nitrogen is needed for making proteins for growth, so living organisms have to get it somehow. This is where the nitrogen cycle comes in — see Figure 1.



N_2 in the atmosphere
Nitrogen-fixing bacteria in roots
Decomposition of urea
Eating
Lightning
Nitrogen-fixing bacteria in the soil
Ammonia
Decomposition
Plant Proteins
Denitrifying bacteria
Ammonium ions
Nitrifying bacteria
Nitrates absorbed by roots
Nitrifying bacteria
Ammonia
Nitrites
Nitrates
Nitrates
Soil

Figure 1: *Diagram showing the nitrogen cycle.*

Tip: Nitrates have the formula NO_3^-. Ammonia has the formula NH_3 and ammonium ions have the formula NH_4^+.

Nitrogen is taken out of the air

Nitrogen in the air has to be turned into mineral ions (such as **nitrates**) in the soil before plants can use it. The process of turning N_2 from the air into nitrogen-containing ions that plants can use is called nitrogen fixation.

Nitrogen fixation happens in two main ways. The first involves lightning. There's so much energy in a bolt of lightning that it's enough to make nitrogen react with oxygen in the air to produce nitrates.

The second way involves **nitrogen-fixing bacteria** — these turn atmospheric N_2 into ammonia. Ammonia forms ammonium ions in solution that plants can use. Some nitrogen-fixing bacteria live in the soil. Others live in nodules (swellings) on the roots of legume plants, e.g. peas and beans. When legume plants decompose, the nitrogen stored in them and in their nodules is returned to the soil (see next page). Nitrogen-containing ions can also leak out of the nodules during plant growth. The bacteria have a **mutualistic** relationship (see page 281) with the plants — the bacteria get food (sugars) from the plants, and the plants get nitrogen-containing ions from the bacteria to make into proteins.

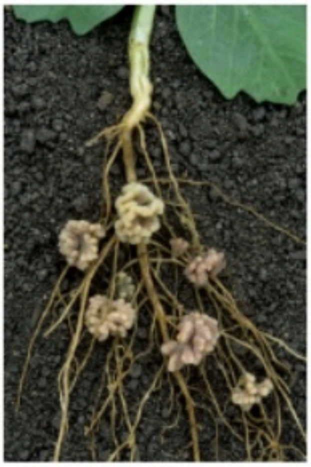


Figure 2: *Photo showing pea plant root nodules. The nodules contain nitrogen-fixing bacteria.*

Nitrogen moves through food chains

Plants absorb nitrogen-containing ions from the soil (or from their root nodules in the case of legumes) and use the nitrogen in them to make proteins. Nitrogen is then passed along food chains in the form of proteins, as animals eat plants (and each other).

Decomposers (bacteria and fungi in the soil) break down proteins in rotting plants and animals, and urea in animal waste, and turn them into ammonia. **Nitrifying bacteria** turn ammonia in decaying matter into nitrites or nitrites into nitrates. These processes return nitrogen to the soil (in the form of ions that can be taken up by plants) so the nitrogen in the organisms is recycled.

Nitrogen is returned to the air

Denitrifying bacteria turn nitrates back into N_2 gas. This is of no benefit to living organisms. Denitrifying bacteria are often found in waterlogged soils.

Increasing the soil nitrate content

Like all plants, crops take up nitrates from the soil as they grow. But crops are harvested, rather than being left to die and decompose, so the nitrogen they contain isn't returned to the soil. Over time, the nitrogen content of the soil decreases, leading to poor crop growth and deficiency diseases. So farmers have ways of increasing the amount of nitrates in the soil to help their crops grow better. For example:

Crop rotation

This is where, instead of growing the same crop in a field year after year, different crops are grown each year in a cycle. The cycle usually includes a nitrogen-fixing crop (e.g. peas or beans), which helps to put nitrates back into the soil for another crop to use the following year.

Fertilisers

Spreading animal manure or compost on fields recycles the nutrients left in plant and animal waste and returns them to the soil through decomposition. Artificial fertilisers containing nitrates (and other mineral ions needed by plants) can also be used, but these can be expensive.

Tip: Nitrites are NO_2^- ions.

Tip: Different species of nitrifying bacteria are responsible for producing nitrites and nitrates. Both nitrites and nitrates can be taken up and used by plants.

Exam Tip
Make sure you learn the different types of bacteria involved in the nitrogen cycle (nitrogen-fixing, decomposers, nitrifying and denitrifying) and what each type does.

Tip: As part of crop rotation, fields can also be left 'fallow' (not sown with a crop) for a year. In 'improved fallow' systems, the fallow field is planted with a fast-growing legume that isn't a crop.

Practice Questions — Fact Recall

Q1 a) Describe the role of nitrifying bacteria in the nitrogen cycle.

b) How are the roles of decomposers and nitrifying bacteria linked?

Q2 What type of bacteria are responsible for turning nitrates in the soil back into nitrogen gas?

Practice Question — Application

Q1 A gardener grows vegetables in raised beds. She grows the same vegetables in each bed every year for three years. Although she uses fertilisers, she finds that she is unable to harvest as many vegetables from the beds each year. Suggest and explain one thing the gardener could do differently to increase the size of her harvest.

Learning Objective:

- **H** Be able to evaluate the use of indicator species as evidence to assess the level of pollution, including:
  - **H** clean water — stonefly, freshwater shrimps;
  - **H** polluted water — bloodworm, sludgeworm;
  - **H** air quality — different species of lichen, blackspot fungus on roses.

Specification Reference 9.16B

4. Indicator Species Higher

The presence or absence of certain organisms in an area can be monitored and used as an indicator of pollution. Read on to find out more...

What are indicator species?

Some organisms are very sensitive to changes in their environment and so can be studied to see the effect of human activities — these organisms are known as indicator species. Indicator species can be used to show the levels of water or air pollution.

Indicator species used to assess water pollution

If raw sewage or fertilisers containing nitrates are released into a river, the microorganisms in the water increase in number and use up the oxygen (as a result of eutrophication, see page 293).

Some invertebrate animals, like stonefly larvae and freshwater shrimps are good indicators for water pollution because they're very sensitive to the concentration of dissolved oxygen in the water. If you find stonefly larvae in a river, it indicates that there's plenty of oxygen and the water is clean.

Other invertebrate species have adapted to live in polluted conditions — so if you see a lot of them you know there's a problem. E.g. bloodworms and sludgeworms indicate a very high level of water pollution.

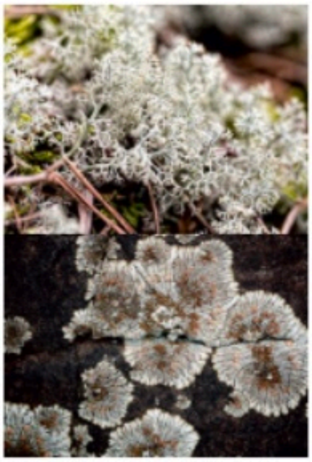


Figure 1: *A bushy lichen (top) and a crusty lichen (bottom).*

Indicator species used to assess air pollution

Air pollution can be monitored by looking at particular types of lichen that are very sensitive to the concentration of sulfur dioxide in the atmosphere. Sulfur dioxide is a pollutant released from car exhausts, power stations, etc. The number and type of lichen at a particular location will indicate how clean the air is. E.g. the air is clean if there are lots of lichen — especially bushy lichen (see Figure 1) which need cleaner air than crusty lichen.

Blackspot fungus is found on rose leaves. It is also sensitive to the level of sulfur dioxide in the air (sulfur dioxide kills it) so its presence will indicate clean air.

Exam Tip H

You might get some data on indicator species in the exam, to which you'll need to apply your knowledge to interpret. E.g. data showing there are more lichen species further away from a city centre may be because outside the city centre, there is less pollution and the air contains less sulfur dioxide.

Methods for using indicator species

There are a couple of ways of using indicator species to measure pollution:

- You could do a simple survey to see if a species is present or absent from an area. This is a quick way of telling whether an area is polluted or not, but it's no good for telling how polluted an area is.
- Counting the number of times an indicator species occurs in an area will give you a numerical value, allowing you to see roughly how polluted one area is in comparison with another.

Pros and cons of indicator species

Using indicator species is a simple and cost-effective way of saying whether or not an area is polluted.

But indicator species can't give accurate figures for exactly how much pollution is present. There may also be factors other than pollution playing a role in the presence or absence of a species in an environment — for example, competition from other organisms or the amount of food available. Sometimes, it's better to use non-living indicators. For example:

Tip: **H** For more on factors that affect the distribution or population size of a species, see pages 283-284.

Examples **Higher**

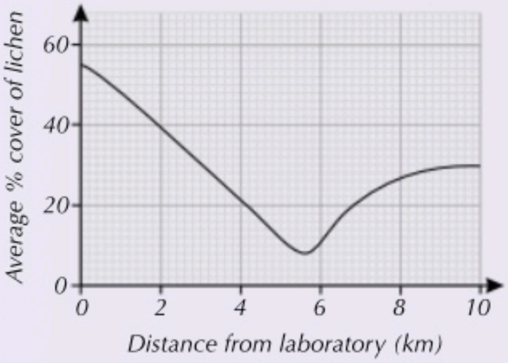
- Dissolved oxygen meters and chemical tests are used to accurately measure the concentration of dissolved oxygen in water, to show how the level of water pollution is changing.
- Electronic meters and various laboratory tests are also used to accurately measure the concentration of sulfur dioxide in air, to show how air pollution is changing.

Practice Questions — Application

Q1 A student is sampling the water in a local stream. He does not find any freshwater shrimp in the stream. He says "This means the water in the stream must be polluted". Is the student's statement correct? Explain your answer.

Q2 Lichen grow on tree trunks. One way of investigating the amount of lichen in an area is to measure how much of a sample of tree trunks are covered in lichen (percentage cover).

In an experiment, scientists recorded the percentage cover of lichen on trees outside their laboratory (0 km) and at different locations up to a distance of 10 km away. A graph produced from their results is shown below.



There is a power station somewhere within the area the scientists studied. By looking at the graph, how far from the laboratory would you expect the power station to be? Explain your answer.

Learning Objectives:

- Be able to explain the effects of temperature, water content and oxygen availability on the rate of decomposition in composting.
- Be able to explain the effects of temperature, water content and oxygen availability on the rate of decomposition in food preservation.
- Be able to calculate rate changes in the decay of biological material.

Specification References
9.17B – 9.19B

5. Decomposition

Decomposition (also known as decay) is the process of breaking down dead plant and animal matter and animal waste. It's essential for keeping nature's cycle of nutrients going...

Factors affecting the rate of decomposition

Nearly all decomposition is carried out by microorganisms like bacteria and fungi. The rate of decomposition depends on three main things:

Temperature

Warmer temperatures make things decompose more quickly because they increase the rate that the microbial enzymes involved in decomposition work.

If it's too hot though, decomposition slows down or stops because the enzymes are denatured (see page 37) and the organisms die. Really cold temperatures slow the rate of decomposition too.

Water availability

Decay takes place faster in moist environments because the organisms involved in decay need water to survive and carry out biological processes.

Tip: Respiration is the process of releasing energy from glucose. Aerobic respiration requires oxygen. There's more on respiration on pages 270-272.

Oxygen availability

The rate of decomposition is faster when there's plenty of oxygen available. Many microorganisms need oxygen to respire, which they need to do to survive. Some microorganisms don't need oxygen to respire, but decomposition involving these organisms happens more slowly anyway.

Compost

Compost is decomposed organic matter (e.g. food waste) that is used as a natural fertiliser for crops and garden plants. It recycles nutrients back into the soil — giving you a lovely garden and improving crop growth.

Compost is produced quickest in warm, moist conditions when there's plenty of oxygen available. Compost bins create the ideal conditions for decomposers. For example, some have mesh sides to increase the oxygen availability — see Figure 1. Gardeners keep the decomposing material moist and heat is generated by the decomposers themselves. Some compost bins are insulated to increase the temperature further.

Tip: Compost can be kept moist by adding water or by keeping it covered in warm weather to prevent evaporation.

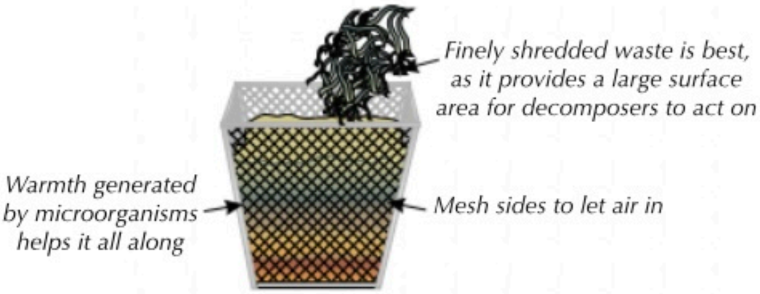

Finely shredded waste is best, as it provides a large surface area for decomposers to act on
Warmth generated by microorganisms helps it all along
Mesh sides to let air in

Figure 1: *A compost bin provides the right conditions for microorganisms to work.*

Food preservation methods

To preserve food, we use methods that slow decomposition by making the oxygen availability, water content and temperature less suitable for microorganisms' survival and reproduction.

Examples

- Storing foods in a fridge or freezer lowers the temperature of the food. This slows down the decomposers' rate of reproduction (or stops it altogether in the case of freezing).
- Storing food in airtight cans stops microorganisms getting in. Once the food is in, the cans are sealed, and sterilised (by exposing them to a high pressure and temperature) to kill any microorganisms present.
- Vacuum packing removes the air from the plastic packaging the food is stored in. This stops any microorganisms in the packaging from being able to respire aerobically.
- Drying food removes the water that microorganisms need to survive and reproduce, as does adding salt or sugar, which causes the microorganisms to lose water by osmosis (see p.49-50).

Figure 2: *Different methods of preserving food. Vacuum packed ham (top). Dried apple rings (bottom)*

Calculating the rate of decay

You need to be able to calculate the rate at which biological material decays. There are different ways of doing this. Just remember that rate is a measure of how much something changes over time (see page 330) — so you need to divide the quantity that changes by the time it takes to change.

Example

A block of cheese was left out of the fridge. The graph in Figure 3 shows the amount of mould that formed on the cheese. Moulds are fungi that decompose the cheese.

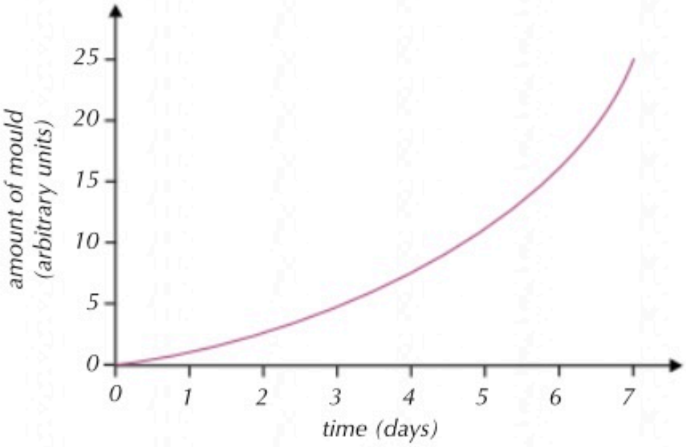


Figure 3: *Graph to show the amount of mould formed on a block of cheese over time.*

Tip: There are different ways in which you could measure the amount of decay, e.g. you could also measure the percentage loss or change in mass.

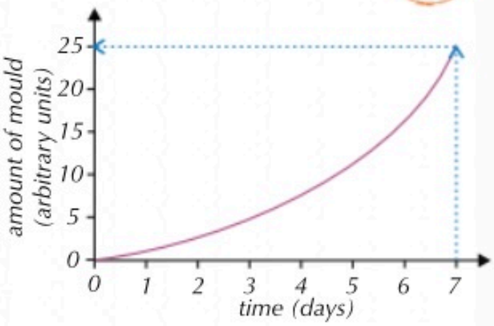
Tip: There's more on calculating rates from graphs on page 330.

Tip: 'Units of mould day^{-1}' means 'units of mould per day'.

Calculate the average rate at which the cheese decomposed during the first week, giving your answer as units of mould day^{-1}.

1. One week = 7 days, so find 7 days on the *x*-axis.
2. Draw a straight line from there up to the curve of the graph, and then another straight line across to the *y*-axis. Read off the amount of mould that had formed...

   = 25 arbitrary units



3. Divide the amount of mould by the number of days.

   25 ÷ 7 = 3.5714... = **3.6 units of mould day^{-1}**.

You might get asked to calculate the change in the rate of decomposition during two different time periods. To do this, just subtract the lower rate from the higher rate.

Example

A compost heap decays at a rate of 0.25% day^{-1} in summer.
The same compost heap decays at a rate of 0.12% day^{-1} in winter.
So the difference in the rate of decomposition between summer and winter is:

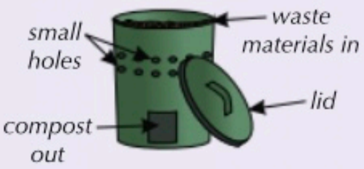
$$0.25 - 0.12 = \mathbf{0.13\%\ day^{-1}}.$$

Practice Questions — Application

Q1 Explain why:

- a) dried pasta keeps longer than fresh pasta.
- b) salted fish keeps longer than unsalted fish.

Q2 Gary recycles his garden waste by making it into compost. He does this in his garden using this compost bin:



- a) Suggest why the compost bin has small holes in it.
- b) Gary's neighbour told him that he should always keep the lid on his compost bin to stop water vapour escaping out of the bin. Explain how the presence of water vapour would help compost to be made.

Figure 4: *Compost bins can come in lots of different shapes and sizes.*

Topic 9b Checklist — Make sure you know...

The Carbon Cycle

☐ How materials cycle through both the biotic (living) and abiotic (non-living) parts of an ecosystem.

☐ That the carbon cycle constantly recycles carbon between the air and living organisms (in food chains) through the processes of photosynthesis, eating, decomposition, respiration and combustion.

☐ That decomposers such as microorganisms are important in the carbon cycle because they release carbon (as carbon dioxide) from dead matter and organic waste.

The Water Cycle

☐ The importance of the water cycle in making water available for living organisms and the processes involved in this, including: evaporation, transpiration, condensation and precipitation.

☐ How potable water (water that's suitable for drinking) can be produced in areas of drought through desalination (the removal of salt from salt water).

☐ Methods of desalination, e.g. thermal desalination and reverse osmosis.

The Nitrogen Cycle

☐ How nitrogen from the air is turned into mineral ions (e.g. nitrates) in the soil that can be taken up by plants.

☐ How bacteria are involved in the nitrogen cycle — including the roles of nitrogen-fixing bacteria, decomposers, nitrifying bacteria and denitrifying bacteria.

☐ How crop rotation and fertilisers can be used to increase the amount of nitrates available for uptake by plants.

Indicator Species

☐ **H** That indicator species are living organisms which can be used to assess pollution in an area.

☐ **H** That the presence of stonefly larvae and freshwater shrimp indicate clean water.

☐ **H** That the presence of bloodworm and sludgeworm in water indicate water pollution.

☐ **H** That the presence of lichen (in particular bushy lichen) or blackspot fungus on roses indicates a low level of sulfur dioxide in the atmosphere, which suggests that the air is clean.

☐ **H** The pros and cons of using indicator species to assess pollution.

Decomposition

☐ How temperature, water content and oxygen availability affect the rate of decomposition and how an understanding of these factors can be applied to making compost and food preservation.

☐ How to calculate rate changes in the decay of biological material.

Exam-style Questions

1 Bacteria play an important role in the nitrogen cycle.

(a) Which of the following describes the role of nitrogen-fixing bacteria in the nitrogen cycle?

A Converting ammonia in decaying matter into nitrates.
B Converting nitrogen in the air into ammonia.
C Converting nitrates in the soil back into nitrogen gas.
D Breaking down nitrogen compounds in decaying matter into ammonia.

(1 mark)

(b) Some nitrogen-fixing bacteria live in the root nodules of legume plants, such as peas and beans.

Describe the relationship between the nitrogen-fixing bacteria and the legume plants.

(2 marks)

2* **Figure 1** shows how a particular food chain is part of the carbon cycle.

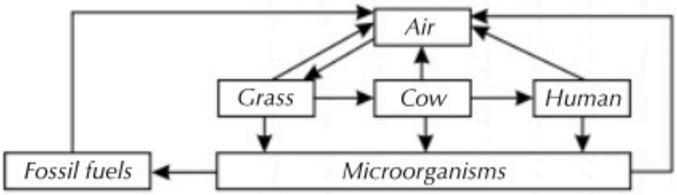


Figure 1

Use the information in **Figure 1** and your own knowledge to describe the processes in which carbon is cycled between this food chain, other living organisms and the air.

(6 marks)

3 Reverse osmosis uses high pressures to move water molecules in the opposite direction to ordinary osmosis. It is a method of desalination.

(a) Explain what is meant by the term desalination.

(1 mark)

(b) (i) Use your knowledge of osmosis to explain how reverse osmosis can be used to produce pure water from sea water.

(2 marks)

(ii) Explain how fresh water is produced from sea water in the water cycle.

(3 marks)

4 The students in a school gardening club decide to investigate whether the location of their compost bin affects the rate at which compost is produced.

The students fill two identical compost bins with the same type and amount of fresh vegetable waste. They place one bin in an area of the garden that gets full sunshine and the other bin in the shade. All other variables are controlled. They then measure the mass of each bin on a weekly basis for 12 weeks.

The students plotted the percentage loss of mass for each bin over the 12 week period. Their graph is shown in **Figure 2**.

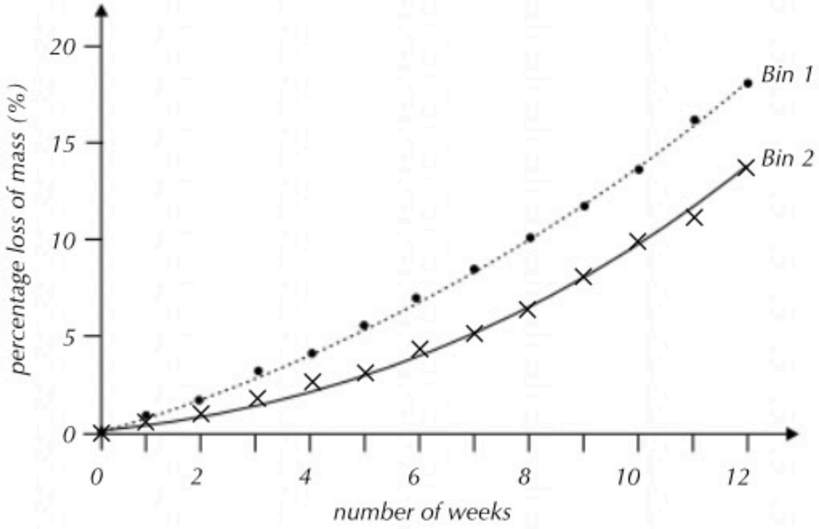


Figure 2

(a) (i) Suggest why the students decide to plot the percentage loss of mass each week rather than the total loss of mass in grams for each bin.

(1 mark)

(ii) Calculate the average daily rate of decay for Bin 1 over the first 8 weeks of the experiment. Give your answer to 2 decimal places and in % day^{-1}.

(2 marks)

(b) Suggest an explanation as to why the bins lost mass over the course of the experiment.

(3 marks)

(c) State which of the two bins is likely to have been placed in the area of full sunshine. Explain your answer.

(3 marks)

(d) One of the students in the gardening club notices blackspot fungus growing on the rose plants in the school garden.

The student is concerned that the growth of the fungus indicates that the local air quality is poor. Do you agree with the student? Explain your answer.

(2 marks)

Practical Skills

1. Measuring Substances

As part of GCSE Biology, you'll have to carry out eight 'Core Practicals'. You'll need to know how to use various pieces of apparatus and carry out different scientific techniques. You could also be asked about the Core Practicals in your exams. Luckily, they're all are covered in this book, and the next few pages cover some of the techniques that you'll need to know about.

Tip: The Core Practicals in this book are marked with a big stamp like this...

CORE PRACTICAL

The practicals that you do in class might be slightly different to the ones in this book (as it's up to your teacher exactly what method you use), but they'll cover the same principles and techniques.

Measuring the mass of a solid

To weigh a solid, start by putting the container you are weighing your substance into on a balance. Set the balance to exactly zero and then weigh out the correct amount of your substance. Easy peasy.

Measuring temperature

You can use a thermometer to measure temperature. Make sure that the bulb of the thermometer is completely submerged in the substance you're measuring and that you wait for the temperature to stabilise before you take your initial reading. Read off the scale on the thermometer at eye level to make sure it's correct.

Tip: When you're reading off a scale, write down the value of the graduation that the amount is closest to. If it's exactly halfway between two values, round up.

Measuring length

Length can be measured in different units (e.g. mm, cm, m). Smaller units have a higher degree of accuracy, e.g. it's more accurate to measure the length of a potato cylinder to the nearest mm than the nearest cm. You'll need to decide on the appropriate level of accuracy for your experiment. It's also important to choose the right equipment — e.g. a ruler's probably best for small things, but a tape measure might be better for larger distances.

Tip: You need to be able to calculate areas as well as length. See page 181 and page 256 for more.

Measuring the volume of a liquid

There's more than one way to measure the volume of a liquid. Whichever method you use, always read the volume from the bottom of the meniscus (the curved upper surface of the liquid) when it's at eye level.

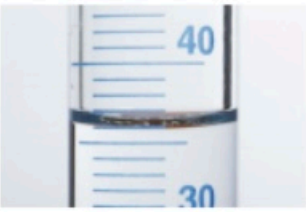
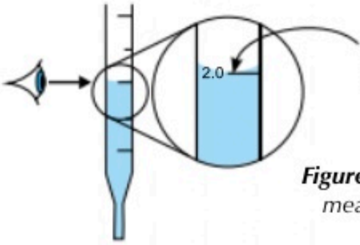


Figure 1: *The meniscus of a fluid in a measuring cylinder, viewed at eye level.*



Read volume from here — the bottom of the meniscus.

Figure 2: *The technique for correctly measuring the volume of a liquid.*

Measuring cylinders

Measuring cylinders come in all different sizes. Make sure you choose one that's the right size for the measurement you want to make. It's no good using a huge 1 dm^3 cylinder to measure out 2 cm^3 of a liquid — the graduations will be too big, and you'll end up with massive errors. It'd be much better to use one that measures up to 10 cm^3.

Pipettes

Pipettes are used to suck up and transfer volumes of liquid between containers. Dropping pipettes are used to transfer drops of liquid. Graduated pipettes are used to transfer accurate volumes. A pipette filler (see Figure 3) is attached to the end of a graduated pipette, to control the amount of liquid being drawn up.

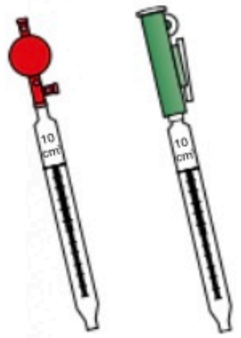


Figure 3: *Graduated pipettes with two different types of pipette filler attached.*

Tip: You could use a dropping pipette if you just wanted to transfer a couple of drops of liquid and didn't need it to be particularly accurate, for example, if you were adding an indicator to a mixture (see below).

Measuring the volume of a gas

There are a few different ways of measuring the volume of a gas. However you do it, it's key that you make sure that the equipment is set up so that none of the gas can escape, otherwise your results won't be accurate.

Gas syringes

To accurately measure the volume of gas, you should use a gas syringe (see Figure 4).

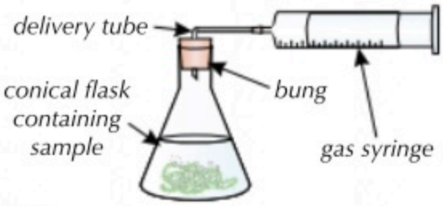


Figure 4: *A gas syringe attached to a conical flask.*

Displacement of water

As an alternative to using a gas syringe, you can use an upturned measuring cylinder filled with water. The gas will displace the water so you can read the volume off the scale.

Counting the bubbles

You could also count the number of bubbles produced. This method is less accurate because the bubbles could be different sizes and, if they're produced quickly, you might miss some. But it will give you relative amounts of gas to compare results.

Measuring the pH of a substance

The method you should use to measure pH depends on your experiment:

Indicator dyes

Indicators are dyes that change colour depending on whether they're in an acid or an alkali. You use them by adding a couple of drops of the indicator to the solution you're interested in. Universal indicator is a mixture of indicators that changes colour gradually as pH changes — see Figure 5. It's useful for estimating the pH of a solution based on its colour.

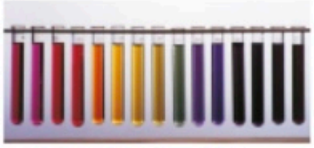


Figure 5: *A set of test tubes containing liquids at a range of pH levels with universal indicator added.*

Indicator paper

Indicator paper is useful if you don't want to colour the entire solution that you're testing. It changes colour depending on the pH of the solution it touches. You can also hold a piece of damp indicator paper in a gas sample to test its pH.

Tip: Blue litmus paper turns red in acidic conditions and red litmus paper turns blue in alkaline conditions.

pH meters

pH meters have a digital display that gives an accurate value for the pH of a solution.

Measuring time

You should use a stopwatch to time experiments. These measure to the nearest 0.1 s, so are pretty sensitive. Make sure you start and stop the stopwatch at exactly the right time.

Tip: It's a good idea to get the same person to do the timing for repeat experiments, so the results are precise.

2. Heating Substances and Using Potometers

Lots of scientific experiments involve heating one or more of the substances involved. The method of heating used depends on the substance being heated and what temperature it needs to be heated to. Potometers are handy pieces of apparatus that are used to measure how much water a plant takes up.

Bunsen burners

Tip: Some things take a long time to cool down, and you can't necessarily tell by looking whether they're hot or cold. So, after heating equipment, you should always handle it with tongs so you don't get burnt.

Bunsen burners are good for heating things quickly. You can easily adjust how strongly they're heating. But you need to be careful not to use them if you're heating flammable substances as the flame means the substance would be at risk of catching fire.

To use a Bunsen burner, you should first connect it to a gas tap, and check that the hole is closed. Place it on a heat-proof mat. Next, light a splint and hold it over the Bunsen burner. Now, turn on the gas. The Bunsen burner should light with a yellow flame. The more open the hole is, the more strongly the Bunsen burner will heat your substance. Open the hole to the amount you want. As you open the hole more, the flame should turn more blue.

Tip: Whenever you use a Bunsen burner, you should wear safety goggles to protect your eyes.

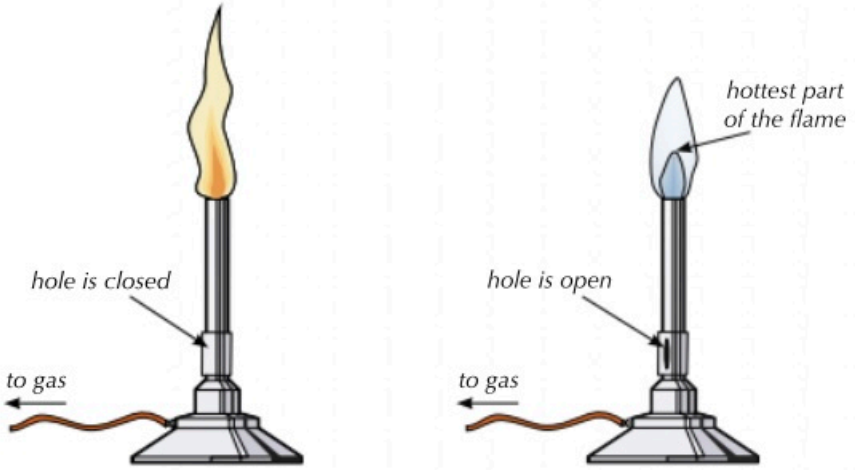


Figure 1: *A Bunsen burner with the hole closed (left) and the hole open (right).*

If your Bunsen burner is alight but not heating anything, make sure you close the hole so that the flame becomes yellow and clearly visible. Use the blue flame to heat things. If you're heating a vessel in the flame, hold it at the top (e.g. with tongs) and point the opening away from yourself (and others). If you're heating something over the flame (e.g. a beaker of water), you should put a tripod and gauze over the Bunsen burner before you light it, and place the vessel on this.

Figure 2: *An electric heater.*

Electric heaters

Electric heaters are often made up of a metal plate that can be heated to a specified temperature. The vessel containing the substance you want to heat is placed on top of the hot plate. The vessel is only heated from below, so you'll usually have to stir the substance inside to make sure it's heated evenly.

Water baths

A water bath is a container filled with water that can be heated to a specific temperature. A simple water bath can be made by heating a beaker of water over a Bunsen burner and monitoring the temperature with a thermometer. However, it is difficult to keep the temperature of the water constant.

An electric water bath will monitor and adjust the temperature for you. To use one, start by setting the temperature on the water bath, and allow the water to heat up. To make sure it has reached the right temperature, use a thermometer. Place the vessel containing your substance in the water bath using a pair of tongs. The level of the water outside the vessel should be just above the level of the substance inside the vessel. The substance will then be warmed to the same temperature as the water.

As the substance in the vessel is surrounded by water, the heating is very even. Water boils at 100 °C though, so you can't use a water bath to heat something to a higher temperature than this — the water won't get hot enough.

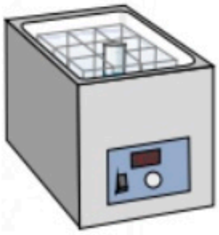


Figure 3: *A typical water bath.*

Measuring water uptake with a potometer

A potometer is a special piece of apparatus used to measure the water uptake of a plant. Here's how to set one up:

1. Cut a shoot underwater to prevent air from entering the xylem. Cut it at a slant to increase the surface area available for water uptake.
2. Assemble the potometer in water and insert the shoot under water, so no air can enter.
3. Remove the apparatus from the water but keep the end of the capillary tube submerged in a beaker of water.
4. Check that the apparatus is watertight and airtight.
5. Dry the leaves, allow time for the shoot to acclimatise and then shut the tap.
6. Remove the end of the capillary tube from the beaker of water until one air bubble has formed, then put the end of the tube back into the water.
7. As the shoot takes up water, the air bubble will move along the capillary tube. So a potometer can be used to estimate the transpiration rate of a plant. There's more about this on page 211.

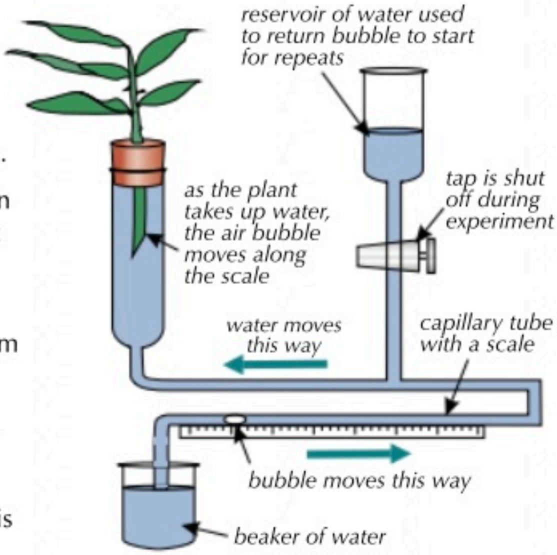

reservoir of water used to return bubble to start for repeats
as the plant takes up water, the air bubble moves along the scale
tap is shut off during experiment
water moves this way
capillary tube with a scale
bubble moves this way
beaker of water

Figure 4: *A potometer set up and ready to use.*

Tip: If there are air bubbles in the apparatus or the plant's xylem, it will affect your results. That's why the whole process of setting up a potometer is done underwater.

Tip: There are different types of potometer available. They won't all look like the one shown in Figure 4.

Figure 5: *Students using a potometer.*

3. Calculating Fields of View and Scientific Drawings of Equipment

A couple more practical techniques for you...

Calculating fields of view

When you look down a microscope, the circular area that's visible is called the 'field of view' (FOV). If you know the size of the field of view, you can estimate the size of your specimen. Here's how you measure the field of view:

- Position a clear ruler on the microscope stage.
- Select the lowest-powered objective lens and follow the steps on page 29 to bring the ruler into focus.
- Measure the diameter of the field of view using the ruler.

You can now remove the ruler and refocus the microscope (using the same objective lens) on a slide containing your specimen. You can estimate the size of the specimen by estimating how many times it fits into the field of view.

Tip: The 'cells' in Figure 1 are a lot bigger than real cells. That's just so you can see what's going on easily.

Tip: To get the diameter of the FOV or the cells in μm, divide the diameter in mm by 1000.

Example

The field of view in Figure 1 measures 5 mm in diameter. Around 7 'cells' fit across it. So each 'cell' measures approximately: 5 ÷ 7 = **0.7 mm** in diameter.

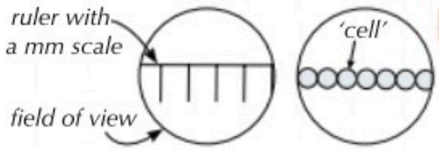


Figure 1: *Using the field of view to estimate the size of a specimen.*

If you need to look at the specimen under a higher magnification, you'll need to recalculate the field of view using this formula:

$$\text{FOV at higher magnification} = \frac{\text{low power magnification}}{\text{higher power magnification}} \times \text{FOV at low magnification}$$

So if your FOV is 5 mm under a magnification of × 40, at a magnification of × 100 it would be: (40 ÷ 100) × 5 = 2 mm.

Tip: The magnification here is not just the objective lens magnification — it's the objective lens magnification × the eyepiece lens magnification (see p.30).

Drawing equipment

When you're writing out a method for an experiment, it's always a good idea to draw a labelled diagram showing how your apparatus will be set up. The easiest way is to use a scientific drawing, where each piece of apparatus is drawn as if you're looking at its cross-section (with no shading or colouring).

Tip: The pieces of glassware are drawn without tops, so they aren't sealed. If you want to draw a closed system, remember to draw a bung in the top.

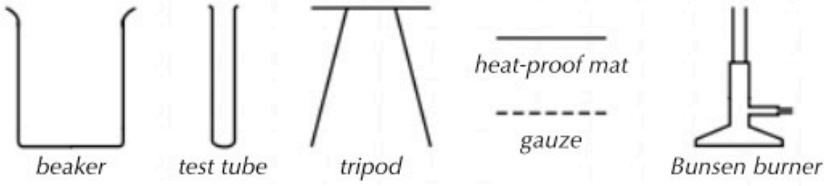


Figure 2: *Scientific diagrams of some basic laboratory equipment.*

4. Sampling

When you're investigating the population size of a certain organism, or its distribution in an area, using sampling can save you an awful lot of time and effort. Read on for more...

What is sampling?

When you're investigating a population, it's generally not possible to count every single organism in the population. This means that you need to take samples of the population you're interested in. The sample data will be used to draw conclusions about the whole population, so it's important that it accurately represents the whole population. To make sure a sample represents a population, it should be random.

Tip: If a sample doesn't represent the population as a whole, it's said to be biased.

If you're interested in the distribution of an organism in an area, or its population size, you can take population samples in the area you're interested in using quadrats or transects (see pages 285-287).

If you only take samples from one part of the area, your results will be biased — they may not give an accurate representation of the whole area. To make sure that your sampling isn't biased, you need to use a method of choosing sampling sites in which every site has an equal chance of being chosen. For example:

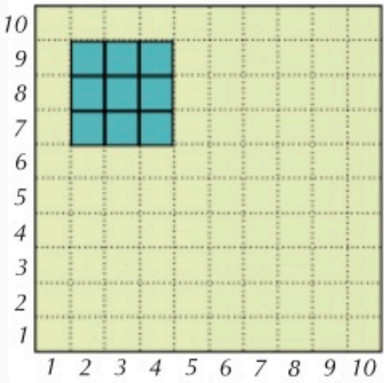
Example

If you're looking at the distribution of plant species in a field...

1. Divide the field into a grid.
2. Label the grid along the bottom and up the side with numbers or letters.
3. Use a random number generator (on a computer or calculator) to select coordinates, e.g. (2,6).
4. Take your samples at these coordinates.

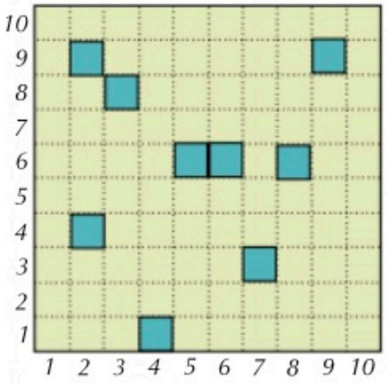
Non-random sampling

Only looks at a small part of the field.



Random sampling

Randomly selects squares from all over the field.



Ran# RanInt
π

Figure 1: *Many scientific calculators have a handy random number generator built in.*

Collecting health data using sampling

As mentioned on the previous page, it's not practical (or even possible) to study an entire human population. You need to use random sampling to choose members of the population you're interested in.

Example

A health professional is investigating how many people diagnosed with type 2 diabetes in a particular country also have heart disease.

1. All the people who have been diagnosed with type 2 diabetes in the country of interest are identified by hospital records. In total, there are 270 196 people.
2. These people are assigned a number between 1 and 270 196.
3. The sample size is decided — e.g. 4250 people.
4. Then a random number generator is used to choose the sample group (e.g. it selects the individuals #72 063, #11 822, #193 123, etc.)
5. The proportion of people in the sample that have heart disease can be used to estimate the total number of people with type 2 diabetes that also have heart disease:
    - Find the number of people in the sample that have heart disease too — here it's 935 people.
    - Work out what proportion of the sample that number is — you can calculate it as a percentage.

$$\text{proportion (\%)} = \frac{\text{number of people sampled with heart disease}}{\text{total number of people sampled}}$$

$$= \frac{935}{4250} \times 100$$

$$= \mathbf{22\%}$$

    - Then use your proportion to estimate the total number of people in the population with both type 2 diabetes and heart disease.

$$= \frac{\text{total population size}}{100} \times \text{proportion (\%)}$$

$$= \frac{270\,196}{100} \times 22$$

$$= \mathbf{59\,443\ people}$$

Tip: See page 11 for more on sample size.

Tip: See page 326 for more on percentages.

Tip: Some calculators have a percentage button, which you can use instead of doing this second calculation.

Continuous sampling

Continuous sampling is when lots of samples are taken in a laboratory experiment at regular intervals over a particular time period. This means you can see what is happening during the experiment, not just the outcome of it. Using a data logger connected to a computer is an example of continuous sampling. Data loggers can be used to measure a range of variables, including temperature, pH and O_2 concentration.

5. Safety and Ethics

Science can be quite dangerous at times, so it's really important that you keep yourself (and others) safe in the lab. Some experiments can also involve ethical issues that you must deal with respectfully and responsibly.

Working safely

Make sure you're working safely in the lab. Before you start any experiment, make sure you know about any safety precautions to do with your method or the chemicals you're using. You need to follow any instructions that your teacher gives you carefully. The chemicals you're using may be hazardous — for example, they might be flammable (catch fire easily), or they might irritate or burn your skin if it comes into contact with them.

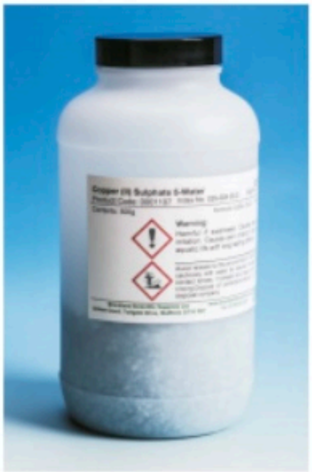


Figure 1: *You'll often see hazard labels on bottles of chemicals. These tell you in what way a chemical is dangerous.*

Make sure that you're wearing sensible clothing when you're in the lab (e.g. open shoes won't protect your feet from spillages). When you're doing an experiment, you should wear a lab coat to protect your skin and clothing. Depending on the experiment, you may need to also wear safety goggles and gloves.

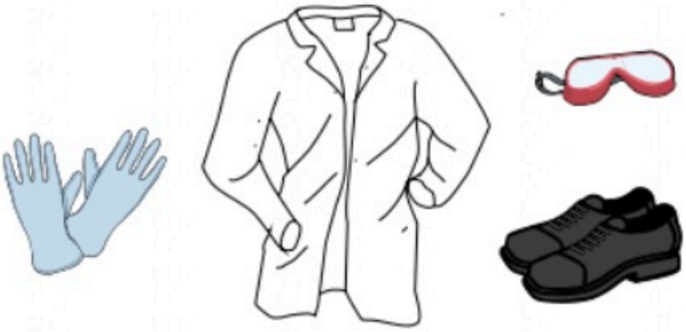


Figure 2: *Diagram showing lab safety gear.*

You also need to be aware of general safety in the lab, e.g. keep anything flammable away from lit Bunsen burners, don't directly touch any hot equipment, handle glassware carefully so it doesn't break, etc. You should also always wash your hands before and after handling living material, and use aseptic techniques (see page 180) when handling bacteria.

Working ethically

You need to think about ethical issues in your experiments.

Any organisms involved in your investigations need to be treated safely and ethically. Animals need to be treated humanely — they should be handled carefully and any wild animals captured for studying (e.g. during an investigation of the distribution of an organism) should be returned to their original habitat. Any animals kept in the lab should also be cared for in a humane way, e.g. they should not be kept in overcrowded conditions.

If you are carrying out an experiment involving other students (e.g. if you were investigating reaction times in response to a stimulus), they should not be forced to participate against their will or feel pressured to take part.

Maths Skills

Maths skills for GCSE Biology

Maths crops up quite a lot in GCSE Biology so it's really important that you've mastered all the maths skills you'll need before sitting your exams. Maths skills are covered throughout this book but here's an extra little section, just on maths, to help you out.

Exam Tip
Around 10% of the marks in the exams will test mathematical skills. That's a lot of marks so it's definitely worth making sure you're up to speed.

1. Calculations

Calculations are the cornerstone of maths in science. So being able to carry them out carefully is pretty important.

Standard form

You need to be able to work with numbers that are written in **standard form**. Standard form is used for writing very big or very small numbers with lots of zeros in a more convenient way. Standard form must always look like this:

This number must always be between 1 and 10. → $A \times 10^n$ ← *This number is the number of places the decimal point moves.*

Examples

- 1 000 000 can be written as 1×10^6.
- 0.017 can be written as 1.7×10^{-2}.

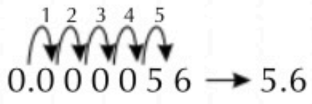
Tip: When you're writing a measurement in standard form, make sure you keep the same number of significant figures (see page 15). E.g. 0.00400 cm^3 = 4.00×10^{-3} cm^3. This'll make sure that you don't lose any accuracy.

You can write numbers in standard form by moving the decimal point. Which direction the decimal point moves, and how many places it moves, is described by '*n*'. If the decimal point has moved to the left, '*n*' is positive. If the decimal point has moved to the right, '*n*' is negative.

Example

Here's how to write out 0.000056 in standard form.

1. Move the decimal point to give the smallest number you can between 1 and 10 — this is '*A*'.



2. Count the number of places the decimal point has moved. In this example, the decimal point has moved five places to the right.
3. Write that number in the place of '*n*'. Remember, if the decimal point has moved to the left, '*n*' is positive. If the decimal point has moved to the right (like in this example), '*n*' is negative.
4. So 0.000056 is the same as 5.6×10^{-5}.

Tip: Double check you've got it right by doing the multiplication — you should end up with the number you started with. So for this example, you'd check $5.6 \times 10^{-5} = 0.000056$. It's easy to do this on your calculator — see the next page for how to type it in.

The key things to remember with numbers in standard form are...

- When 'n' is positive, the number is big. The bigger 'n' is, the bigger the number is.
- When 'n' is negative, the number is small. The smaller 'n' is (the more negative), the smaller the number is.
- When 'n' is the same for two or more numbers, you need to look at the start of each number to work out which is bigger. For example, 4.5 is bigger than 3.0, so 4.5×10^5 is bigger than 3.0×10^5.

There's a special button on your calculator for using standard form in a calculation — it's the 'Exp' button. So if, for example, you wanted to type in 2×10^7, you'd only need to type in: '2' 'Exp' '7'. Some calculators may have a different button that does the same job, for example it could say 'EE' or '$\times 10^x$' instead of 'Exp' — see Figure 1.

Figure 1: *The 'Exp' or '$\times 10^x$' button is used to input standard form on calculators.*

Using ratios

Ratios can be used to compare quantities.

Example

An organism with a surface area to volume ratio of 2 : 1 would theoretically have a surface area twice as large as its volume.

Ratios are usually written like this:

A colon separates one quantity from the other.

$x : y$

x and y stand for the quantities that you want to compare.

Ratios are usually most useful in their simplest (smallest) form. To simplify a ratio, divide each side by the same number. It's in its simplest form when there's nothing left you can divide by to give a whole number ratio.

Tip: When you divide one side of a ratio by an amount, you have to divide the other side by the same number for the ratio to keep the same proportions.

Example

To simplify the ratio 28 : 36, divide both sides by 4.

You get **7 : 9**. ← *You can't divide 7 and 9 by the same number to get two whole numbers, so this must be the ratio's simplest form.*

To compare two ratios, it's best to get the number on the right-hand side of each ratio to be 1. Then you can easily see which ratio is the largest. To get a ratio of x : y in the form n : 1, divide both sides by y.

Tip: If you're not sure what number to divide by to simplify a ratio, start by trying to divide both sides by a small number, e.g. 2 or 3, then check to see if you can simplify your answer further. E.g. you could simplify 28 : 36 by dividing each side by 2 to get 14 : 18. But you could simplify it further by dividing by 2 again to get 7 : 9. You can't simplify the ratio any further, so it's in its simplest form.

Example

Organism A has a surface area to volume ratio of 6 : 1.
Organism B has a surface area to volume ratio of 30 : 9.

To compare the two ratios, you need to write the ratio 30 : 9 in the form of n : 1. To do this, just divide both sides by 9:

$$\begin{tikzcd} 30:9 \arrow[d, bend right, "\begin{array}{r} 30 \div 9 = 3.3\ldots \\ = 3.3 \end{array}"'] \arrow[d, bend left, "9 \div 9 = 1"] \\ 3.3:1 \end{tikzcd}$$

So the ratio of Organism B is equal to **3.3 : 1**. 3.3 is smaller than 6, so Organism A has the larger surface area to volume ratio.

Calculating percentages

Percentages are another way of comparing quantities. They come in handy when you want to compare amounts from different-sized samples.

To give the amount X as a percentage of total amount Y, you need to divide X by Y, then multiply by 100.

Example

The amount of biomass available in the first level of a food chain is 40 kg. 4 kg of this biomass is transferred to the next level of the food chain. What percentage of the original biomass is transferred?

1. You want to give 4 kg as a percentage of 40 kg, so divide 4 by 40:

$$4 \div 40 = 0.1$$

2. Multiply this amount by 100:

$$0.1 \times 100 = \mathbf{10\%}$$

Exam Tip
Rather than having to calculate a percentage, you might be asked to give your answer as a fraction, i.e. X/Y. To simplify a fraction, divide the top and bottom of the fraction by the same number. E.g. 4/40 = (4 ÷ 4)/(40 ÷ 4) = 1/10. To get the fraction as simple as possible, you might have to do this more than once.

Calculating percentage change

When investigating the change in a variable, you may want to compare results that didn't have the same initial value. For example, you may want to compare the change in mass of potato cylinders left in different concentrations of sugar solution, when the cylinders had different initial masses (see p.53). One way to do this is to calculate the percentage change.

To calculate it you use this equation:

$$\text{percentage (\%) change} = \frac{\text{final value} - \text{original value}}{\text{original value}} \times 100$$

Tip: A positive value for percentage change indicates an increase and a negative value indicates a decrease.

Example

A student is investigating the effect of the concentration of sugar solution on potato cells. She records the mass of potato cylinders before and after placing them in sugar solutions of different concentrations. The table below shows some of her results.

Potato cylinder	Concentration (mol/dm^3)	Mass at start (g)	Mass at end (g)
1	0.0	7.5	8.7
2	1.0	8.0	6.8

Which potato cylinder had the largest percentage change?

1. Stick each set of results into the equation:

$$\% \text{ change} = \frac{\text{final value} - \text{original value}}{\text{original value}} \times 100$$

potato cylinder 1: $\frac{8.7 - 7.5}{7.5} \times 100 = 16\%$

potato cylinder 2: $\frac{6.8 - 8.0}{8.0} \times 100 = -15\%$

2. Compare the results.

16% is greater than 15%, so potato cylinder 1 had the largest percentage change.

Tip: The mass at the start is the original value and the mass at the end is the final value.

Tip: A decrease in mass gives a negative value for the percentage change.

Estimating values

Estimating can help you to check your answer is roughly correct. To estimate the answer to a calculation, just round everything off to nice, convenient numbers so that you get a simple calculation that you can do in your head.

Most of the time, you should round the numbers to just one significant figure.

Example

A student calculated the number of stomata per mm^2 on ten different leaves.

The results are shown in the table below.

Leaf	1	2	3	4	5	6	7	8	9	10
Number of stomata/mm^2	245	287	322	185	316	299	178	250	332	420

The student calculates that the mean number of stomata per mm^2 is 283. You could estimate the mean of the data like this:

1. Round the numbers to one significant figure.

200 300 300 200 300 300 200 300 300 400

2. Do the calculation with the rounded numbers.

$(200 + 300 + 300 + 200 + 300 + 300 + 200 + 300 + 300 + 400) \div 10$

$= 2800 \div 10 = \mathbf{280}$

From the estimated calculation, 283 is a sensible answer. If your answer was massively different, you would know that your calculation had gone wrong somewhere.

Exam Tip

By working out an estimate in the exam, you can check that you haven't made any silly mistakes while calculating your answer (like missing out a decimal place along the way) and it could be a lot quicker than typing the whole thing into your calculator again.

2. Algebra

Every so often, biology can involve a bit of rearranging equations and substituting values into equations. It can be easy to make simple mistakes though, so here are a few things to remember...

Algebra symbols

Here's a reminder of some of the symbols that you will come across:

Symbol	Meaning
=	equal to
<	less than
<<	much less than
>	greater than
>>	much greater than
∝	proportional to
~	roughly equal to

Tip: An example of using 'proportional to' can be found on p.206. There are two types of proportion — direct and inverse. When two values are directly proportional to each other, if one increases, the other increases at the same rate. When two values are inversely proportional to each other, if one increases, the other decreases at the same rate.

Using equations

Equations can show relationships between variables. To rearrange an equation, make sure that whatever you do to one side of the equation you also do to the other side.

Tip: The word formula is sometimes used instead of the word equation.

Example

You can find the magnification of something using the equation:
magnification = image size ÷ real size

You can rearrange this equation to find the image size by multiplying each side by the real size: image size = magnification × real size.

Tip: There's more about this equation for magnification on pages 30-31.

To use an equation, you need to know the values of all but one of the variables. Substitute the values you do know into the equation, and do the calculation to work out the final variable. Always make sure the values you put into an equation have the right units.

Example

3.2 cm^3 of blood passes through part of a vein in 30 seconds. Calculate the rate of blood flow through the vein in $\text{cm}^3\,\text{min}^{-1}$. Use the equation:

$$\textbf{rate of blood flow } (\text{cm}^3\,\text{min}^{-1}) = \frac{\textbf{volume of blood } (\text{cm}^3)}{\textbf{time (min)}}$$

1. You want to know the rate per minute so convert 30 seconds into minutes: 30 ÷ 60 = 0.50
2. Substitute the values into the equation:

$$3.2\ \text{cm}^3 \div 0.50\ \text{min} = \mathbf{6.4\ cm^3\ min^{-1}}$$

Tip: Converting all the values into the correct units before putting them into the equation stops you making silly mistakes.

To make sure your units are correct, it can help to write down the units on each line of your calculation.

3. Graphs

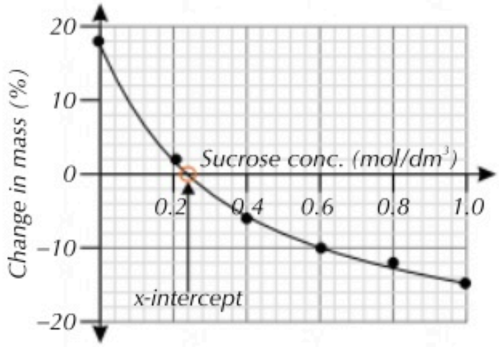
Results are often presented using graphs. They make it easier to see relationships between variables and can be used to calculate other quantities.

Finding the intercept of a graph

The *y*-intercept of a graph is the point at which the line of best fit crosses the *y*-axis. Meanwhile, the *x*-intercept is the point at which the line of best fit crosses the *x*-axis.

Example

A graph can be plotted to show the percentage change in mass of several pieces of potato against the different concentrations of sucrose solution that they were left in overnight.



The approximate concentration of the solution in the potato cells, which is equal to the *x*-intercept, is **0.24 mol/dm³**.

Tip: See pages 52-54 for more on how to carry out this experiment and analyse the results.

Linear graphs

A linear graph is a straight line graph. This means that one of the variables plotted on the axes increases or decreases in relation to the other, which is shown by a straight line. An example of a linear graph is shown in Figure 1.

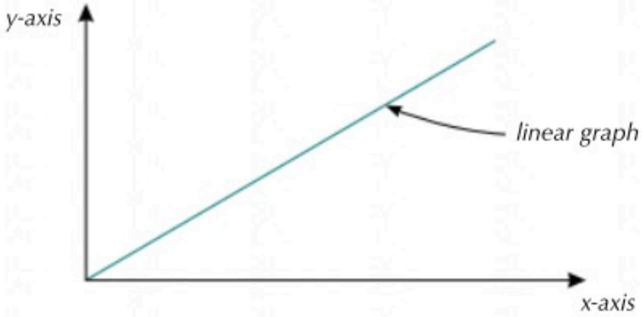


Figure 1: *A linear graph.*

Tip: If one variable increases in proportion with the other (so if *x* is doubled, *y* is doubled, etc.), the graph shows a directly proportional relationship.

Finding the rate

Rate is a measure of how much something is changing over time. Calculating a rate can be useful when analysing your data, e.g. you might want to the find the rate of a reaction. You can find the rate from a graph that shows a variable changing over time by finding the **gradient** (how steep it is).

Tip: The gradient of a graph tells you how quickly the dependent variable changes if you change the independent variable.

For a linear graph, you can calculate the rate by finding the gradient of the line, using the equation:

$$\text{Gradient} = \frac{\text{Change in } y}{\text{Change in } x}$$

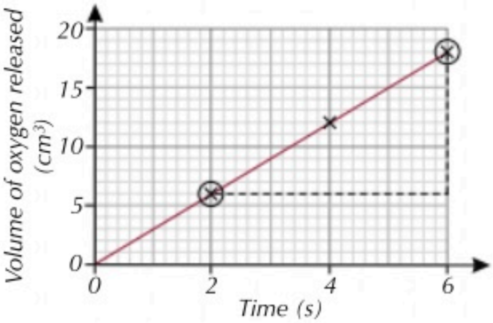
Tip: When using this equation to find a rate, x should always be the time.

Change in y is the change in value on the y-axis and **change in x** is the change in value on the x-axis.

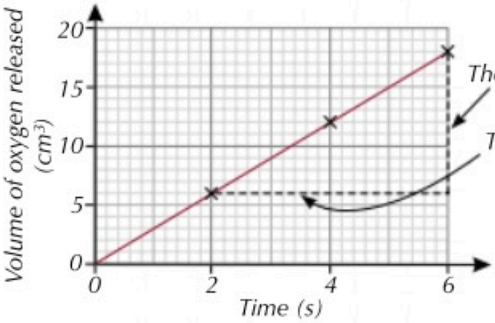
Example

To find the rate at which oxygen is produced in the graph below:

1. Pick two points on the line that are easy to read and a good distance apart.
2. Draw a vertical line down from one point and a horizontal line across from the other to make a triangle.



3. Use the scales on the axes to work out the length of each line. The vertical side of the triangle is the change in y and the horizontal side of the triangle is the change in x.



The change in y is 18 – 6 = 12 cm³.

The change in x is 6 – 2 = 4 s.

So, rate $= \frac{12 \text{ cm}^3}{4 \text{ s}} = \mathbf{3\ cm^3/s}$

Tip: The units for the gradient are the units for y divided by the units for x.

$y = mx + c$

The y-intercept and the gradient of a linear graph can be used to work out the equation of the graph line. The equation of a straight line is given by:

$$y = mx + c$$

y = y-axis value

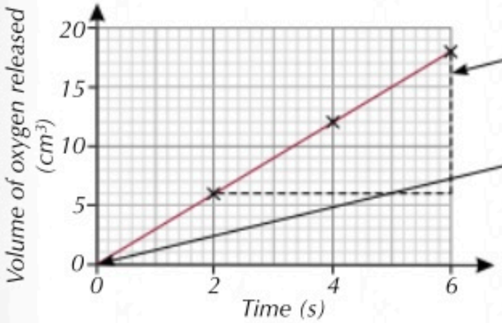
m = gradient

c = y-intercept

x = x-axis value

The equation of the line shows the relationship between the two variables. To work out the equation, you just need to plug in the values for m and c.

Example



The gradient (m) is ($12 \div 4 =$) 3.

The y-intercept (c) is 0.

So the equation for the line is:
$y = 3x + 0$, or just
$y = 3x$

Tip: mx is just the same as writing '$m \times x$'.

Tip: If the straight line passes through the origin of the graph (the point at which the x-axis and y-axis meet), then the y-intercept is just zero.

Tip: You can check your equation is correct using the values of x and y from a point on the graph. Just pop the value for x into the equation and it should give you the value of y.

Exam Help

1. The Exams

Unfortunately, to get your GCSE you'll need to sit some exams. And that's what this page is about — what to expect in your exams.

Exam Tip
Make sure you have a good read through these pages. It might not seem all that important now, but you don't want to get any surprises just before an exam.

Assessment for GCSE Biology

To get your GCSE in Biology you'll have to do some exams that test your knowledge of Biology, your understanding of the Core Practical experiments and how comfortable you are with Working Scientifically. You'll also be tested on your maths skills.

All the content that you need to know is in this book. All the Core Practicals are covered in detail and clearly labelled, examples that use maths skills are marked up, and there are even dedicated sections on Working Scientifically (pages 2-22), Maths Skills (pages 324-331) and Practical Skills (pages 316-323).

Exam Tip
Besides the Core Practicals, there are other practical experiments described in the specification, which you could be tested on. They're also covered in this book.

Grading

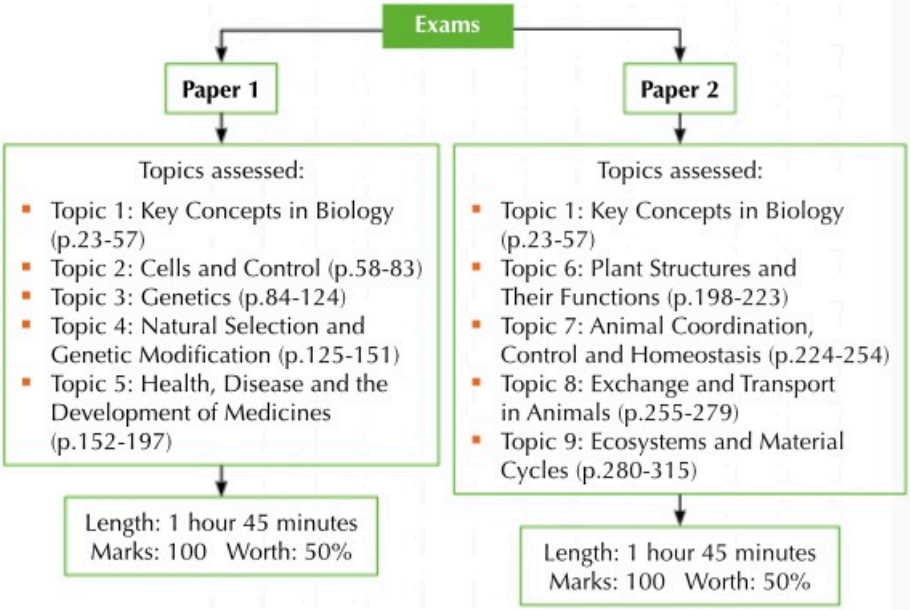
When you sit your exams, you'll be given a grade between 1 and 9 based on your results. 9 is the highest grade, and 1 is the lowest. Which grades you can get will depend on which set of exams you sit — Foundation tier, or Higher tier.

If you take the Foundation tier exams, you can get a grade between 1 and 5, with 5 being the maximum grade you can get. If you sit the Higher tier exams, you can get a grade between 3 and 9.

Exam Tip
The Higher tier papers target grades 4 to 9, however, if you just miss out on the marks needed for a grade 4, then you may be awarded a grade 3.

The exams

You'll sit two separate exams at the end of Year 11 — remember that you could be asked questions on Working Scientifically in either of them.



Exams

Paper 1

Topics assessed:
- Topic 1: Key Concepts in Biology (p.23-57)
- Topic 2: Cells and Control (p.58-83)
- Topic 3: Genetics (p.84-124)
- Topic 4: Natural Selection and Genetic Modification (p.125-151)
- Topic 5: Health, Disease and the Development of Medicines (p.152-197)

Length: 1 hour 45 minutes
Marks: 100 Worth: 50%

Paper 2

Topics assessed:
- Topic 1: Key Concepts in Biology (p.23-57)
- Topic 6: Plant Structures and Their Functions (p.198-223)
- Topic 7: Animal Coordination, Control and Homeostasis (p.224-254)
- Topic 8: Exchange and Transport in Animals (p.255-279)
- Topic 9: Ecosystems and Material Cycles (p.280-315)

Length: 1 hour 45 minutes
Marks: 100 Worth: 50%

Exam Tip
You're allowed to use a calculator in both of your GCSE Biology exams, so make sure you've got one. You should also have a pen, spare pen, pencil and a ruler.

2. Exam Technique

Knowing the science is vitally important when it comes to passing your exams. But having good exam technique will help too...

Time management

Good time management is one of the most important exam skills to have — you need to think about how much time to spend on each question. Check out the length of your exams (you'll find them on the previous page and on the front of your exam papers). These timings give you about 1 minute per mark. Try to stick to this to give yourself the best chance to get as many marks as possible. Don't spend ages struggling with a question if you're finding it hard to answer — move on. You can come back to it later when you've bagged loads of other marks elsewhere.

Exam Tip
You shouldn't really be spending more time on a 1 mark question than on a 4 mark question. Use the marks available as a rough guide for how long each question should take to answer.

Reading the question

Make sure you always read the whole question carefully. It can be easy to look at a question and read what you're expecting to see, rather than what it's actually asking you. Read it through before you start answering, and read it once again when you've finished, to make sure your answer is sensible and matches up to what the question is asking.

Remember to pay attention to the marks available too. If it's just a one or two mark question, it'll often only need a single word or phrase as an answer, or a very simple calculation. Questions worth more marks are likely to be longer questions, which need to be clearly structured and will involve writing a short paragraph or a more complicated calculation.

Exam Tip
Don't forget to go back and do any questions that you left the first time round — you don't want to miss out on marks because you forgot to do the question.

Exam Tip
The amount of space given for your answer should also give you an idea about how much you need to write.

Making educated guesses

Make sure you answer all the questions that you can — don't leave any blank if you can avoid it. If a question asks you to tick a box, circle something or draw lines between boxes, you should never, ever leave it blank, even if you're short on time. It only takes a second or two to answer these questions, and even if you're not certain what the answer is you can have a good guess.

Example **Higher**

Look at the question below.

1 Which **one** of these hormones is involved in the menstrual cycle?

A Insulin ☐ **B** LH ☐ **C** Testosterone ☐ **D** Glucagon ☐

(1 mark)

Say you knew that insulin and glucagon help to regulate blood sugar level, but weren't sure about the roles of the other two hormones.

You know the answer isn't insulin or glucagon, so you can ignore those two options. That leaves you with testosterone and LH. If you're not absolutely sure which is involved in the menstrual cycle and which isn't, just have a guess. You won't lose any marks if you get it wrong and there's a 50% chance that you'll get it right.

3. Question Types

If all questions were the same, exams would be mightily boring. So really, it's quite handy that there are lots of different question types. Here are just a few...

Command words

Command words are just the bits of a question that tell you what to do. You'll find answering exam questions much easier if you understand exactly what they mean, so here's a brief summary of the most common ones:

Command word:	What to do:
Give / Name / State	Give a brief one or two word answer, or a short sentence.
Complete	Write your answer in the space given. This could be a gap in an equation or table, or you might have to finish a diagram.
Describe	Write about what something's like, e.g. describe the trend in a set of results.
Explain	Make something clear, or give the reasons why something happens. The points in your answer need to be linked together, so you should include words like because, so, therefore, due to, etc.
Calculate	Use the numbers in the question to work out an answer.
Suggest	Use your scientific knowledge to work out what the answer might be.
Compare	Give the similarities or differences between two things.
Compare and contrast	Give the similarities and differences between two things.
Devise	Come up with or plan an experimental procedure using your existing scientific knowledge.
Estimate	Use rounded numbers to work out an approximate answer.
Evaluate	Review some information or data and use your findings to draw a conclusion about something — this usually involves, e.g. weighing up advantages and disadvantages.

Exam Tip
When you're reading an exam question, you might find it helpful to underline the command words. It can help you work out what type of answer to give.

Exam Tip
It's easy to get describe and explain mixed up, but they're quite different. For example, if you're asked to describe some data, just state the overall pattern or trend. If you're asked to explain data, you'll need to give reasons for the trend.

Exam Tip
Some questions will ask you to 'Use Figure X' to answer them. If so, you must refer to the Figure or you won't get the marks.

Core Practicals

The Core Practicals are eight experiments that you need to cover during your lessons. At least 15% of the total marks in your exams will be for questions that test your understanding of these experiments and the techniques involved in them. Here are some basic areas you might be asked about:

- Carrying out the experiment — e.g. planning or describing a method, describing how to take measurements or use apparatus.

Exam Tip
The Core Practical questions are likely to have some overlap with Working Scientifically, so make sure you've brushed up on pages 2-22.

- Risk assessment — e.g. describing or explaining dangers which can arise from the experiment, or safety precautions which should be taken.
- Understanding variables — e.g. identifying control, dependent and independent variables.
- Data handling — e.g. plotting graphs or doing calculations using some sample results provided.
- Analysing results — e.g. making conclusions based on sample results.
- Evaluating the experiment — e.g. making judgements on the quality of results, identifying where mistakes have been made in the method, suggesting improvements to the experiment.

Core Practical questions won't be pointed out to you in the exam, so you'll need to make sure you know the practicals inside out, and can recognise them easily. For an example of a question testing your understanding of a Core Practical, see page 186.

Levels of response questions

Some questions are designed to assess your ability to present and explain scientific ideas in a logical and coherent way, as well as your scientific knowledge. These questions often link together different topics and are worth 6 marks each. These questions will be marked in your exam papers with an asterisk (*).

This type of question is marked using a 'levels of response' mark scheme. Your answer is given a level depending on the number of marks available and its overall quality and scientific content. Here's an idea of how the levels may work out for a 6 mark question:

Example

- An answer that has no relevant information and makes no attempt to answer the question receives no marks.
- A Level 1 answer usually makes one or two correct statements, but does not fully answer the question. For instance, when asked to explain how the features of an organism make it adapted to its environment, it might state one or two correct facts about the organism's features, but not attempt to link them to the environment. These answers receive 1 or 2 marks.
- A Level 2 answer usually makes a number of correct statements, with explanation, but falls short of fully answering the question. It may miss a step, leave out an important fact, or not be organised as logically as it should be. These answers receive 3 or 4 marks.
- A Level 3 answer will answer the question fully, in a logical fashion. It will make a number of points that are explained and related back to the question. Any conclusions it makes will be supported by evidence in the answer. These answers receive 5 or 6 marks.

Exam Tip
It might be useful to write a quick plan of your answer in the spare space of your paper. This can help you get your thoughts in order, so you can write a logical, coherent answer. But remember to cross your plan out after you've written your answer so it doesn't get marked.

Exam Tip
Make sure your writing is legible — you don't want to lose marks just because the examiner couldn't read your handwriting.

Exam Tip
Make sure your writing style is appropriate for an exam. You need to write in full sentences and use fairly formal language.

Make sure you answer the question fully, and cover all points indicated in the question. You also need to organise your answer clearly — the points you make need to be in a logical order. Use specialist scientific vocabulary whenever you can. For example, if you're describing cell division, you'd need to use scientific terms like mitosis and chromosomes. Obviously you need to use these terms correctly — it's no good knowing the words if you don't know what they actually mean.

There are some exam-style questions that use this type of mark scheme in this book (marked up with an asterisk, *, as in the real exams). You can use them to practise writing logical and coherent answers. Use the worked answers given at the back of this book to mark what you've written. The answers will tell you the relevant points you could've included, but it'll be down to you to put everything together into a full, well-structured answer.

Calculations

In the GCSE Biology exams, around 10% of the total marks will come from questions that test your maths skills. Questions that involve a calculation can seem a bit scary. But they're really not that bad. Here are some tips to help you out...

- Show your working — this is the most important thing to remember. It only takes a few seconds more to write down what's in your head and it might stop you from making silly errors and losing out on easy marks. You won't get a mark for a wrong answer, but you could get marks for the method you used to work out the answer.
- Check your answer — a good way to do this is to work backwards through your calculation. You should also think about whether your answer seems sensible — if it's a much bigger or smaller number than you were expecting, you might have gone wrong somewhere.

Figure 1: *A calculator. Under the pressure of an exam it's easy to make mistakes in calculations, even if they're really simple ones. So don't be afraid to put every calculation into the calculator.*

Example

A potato chip weighs 10.2 g at the start of the experiment. At the end of the experiment it weighs 11.6 g. To calculate the change in mass, you'd subtract 10.2 g from 11.6 g — which works out as 1.4 g. You'd expect the answer to be around 1 g, so this seems sensible. To check it though, just add 1.4 to 10.2 — you should end up with 11.6.

- Sometimes you'll be asked to pick some numbers out of a table or read values off a graph to use in your calculation. If so, always read the question carefully so you know exactly what figures you need to use. Make sure you read the headings in the table carefully too (or the axes on the graph) to make sure you understand what's being shown.

Exam Tip
These aren't the only calculations you could be asked to do in an exam — they're just examples of the sort of thing that's likely to come up.

In the exams, you should be prepared to do things like estimate a value, calculate a percentage or a mean, put numbers into equations that you've been given, and recall and use relevant equations.

Answers

Topic 1 — Key Concepts in Biology

Topic 1a — Cells and Microscopy

1. Cell Structure

Page 25 — Fact Recall Questions

Q1 the genetic material / the nucleus

Q2 In the mitochondria.

Q3 protein synthesis

Q4 a) A cell wall, a large vacuole and chloroplasts.

b) A cell wall — supports and strengthens the cell.
A vacuole — maintains the internal pressure to support the cell.
Chloroplasts — contain chlorophyll, which absorbs light for photosynthesis.

Q5 A small loop of DNA (that is not part of the main chromosome).

Q6 a) A long hair-like structure, which rotates to make a bacterium move.

b) To move away from harmful substances.
To move towards nutrients/oxygen.

Page 25 — Application Question

Q1 a) It doesn't contain chloroplasts.

b) It has a cell wall.

2. Specialised Cells

Page 27 — Fact Recall Questions

Q1 acrosome

Q2 To carry the female DNA. To nourish the developing embryo in its early stages.

Q3 It has a haploid nucleus. Its membrane changes structure straight after fertilisation to stop any more sperm getting in.

Page 27 — Application Question

Q1 E.g. to supply enough energy (through aerobic respiration) to move/beat the cilia.

3. Microscopy

Page 33 — Fact Recall Questions

Q1 An electron microscope has a higher magnification and resolution than a light microscope, so it can be used to look at smaller objects.

Q2 To add colour to objects in a cell, making them easier to see.

Q3 Clip the slide to a microscope stage. Select the lowest-powered objective lens. Use the coarse adjustment knob to move the stage up to just below the objective lens. Look down the eyepiece. Use the coarse adjustment knob to move the stage downwards until the image is roughly in focus. Adjust the focus with the fine adjustment knob, until you get a clear image of what's on the slide.

Q4 1 nm = 1×10^{-9} m

Page 33 — Application Questions

Q1 magnification = eyepiece lens magnification × objective lens magnification
= 15 × 40 = **× 600**

Q2 magnification = image size ÷ real size
= 18 ÷ 0.002 = **× 9000**

Q3 image size = magnification × real size
= 400 × 0.08 = **32 mm**

Q4 real size = image size ÷ magnification
= 10.5 ÷ 1500 = 0.007 mm
0.007 mm × 1000 = **7 µm**
The question asks for the answer to be in µm, so to convert mm to µm you need to multiply by 1000.

Q5 magnification = image size ÷ real size
image size = 900 µm ÷ 1000 = 0.9 mm
= 0.9 ÷ (2×10^{-5}) = 0.9 ÷ 0.00002 = **× 45000**
You need both the image size and the real size to be in the same units here, but it doesn't matter whether they're both in mm or both in µm. You could have also done 900 ÷ 0.02 and got the right answer.

Page 35 — Cells and Microscopy Exam-style Questions

1 a) C ***(1 mark)***

b) A eukaryotic cell, e.g. because it has a nucleus/ mitochondria/chloroplasts / it doesn't have plasmids/a circular strand of DNA in the cytoplasm ***(1 mark)***.

c) chloroplasts ***(1 mark)***

2 a) The tail allows the sperm to swim to the egg ***(1 mark)***.

b) A/image width = 33 mm
real width = 55 µm ÷ 1000 = 0.055 mm
magnification = image width ÷ real width
= 33 ÷ 0.055 = **× 600**
(3 marks for correct answer, otherwise 1 mark for 33 mm and 1 mark for correctly converting both measurements into the same units.)
If you got the correct answer of × 600 by converting 33 mm into µm (33 × 1000 = 33000 µm) you would still get the marks here.

c) The real length of the sperm cell is 55 µm. The head is approximately one fifth of the length of the entire cell. 55 µm ÷ 5 = **11 µm**
(accept answers between 9.2 and 13.75 µm)
(2 marks for correct answer, otherwise 1 mark for correctly estimating the head to be between one quarter and one sixth of the size of the whole cell.)

Topic 1b — Biological Molecules and Transport in Cells

1. Enzymes

Page 38 — Fact Recall Questions

Q1 Because they increase the speed of a biological reaction without being changed or used up in the reaction.

Q2 active site

Q3 false

Different enzymes work best at different pHs.

Page 38 — Application Question

Q1 It should slow down the rate of reaction.
This is because heating hexokinase up to a high temperature/50 °C will probably cause the bonds in hexokinase to break and the active site to lose its shape / the enzyme to denature. This would mean that glucose will no longer be able to fit into the active site and the reaction won't be catalysed.

For questions like this you just need to apply your own knowledge — e.g. that enzymes lose their shape at high temperatures and that enzymes need their unique shape to work — to the specific enzyme named in the question.

2. Investigating Enzymatic Reactions

Page 40 — Application Question

Q1 a) a buffer solution

b) The iodine solution would remain browny-orange rather than changing to blue-black.

c) E.g.

$$\text{Rate} = \frac{1000}{\text{time}} = \frac{1000}{120}$$

$$= \mathbf{8.3\ s^{-1}}\ (2\text{ s.f.})$$

If you used 1/time here and got the answer 0.0083 s^{-1}, then you'd still get the marks in an exam.

3. Enzymes in Breakdown and Synthesis

Page 42 — Fact Recall Questions

Q1 false

Digestive enzymes catalyse the breakdown of big molecules into smaller molecules.

Q2 a) lipases

b) glycerol, fatty acids

Page 42 — Application Question

Q1 The protease will break the protein down into amino acids. The amino acids will then react with the ninhydrin, turning the samples from a yellowish colour to a deep-purple colour.

4. Testing for Biological Molecules

Page 45 — Fact Recall Questions

Q1 The solution would change from browny-orange to black or blue-black.

Q2 blue

Page 45 — Application Questions

Q1 reducing sugar

Q2 Transfer some of the food sample into a test tube. Add 2 cm^3 of ethanol to the test tube. Shake the test tube well for about 1 minute until the test substance dissolves. Pour the solution into a test tube containing 2 cm^3 of distilled water. If there are any lipids present, they will precipitate out of the liquid and show up as a milky emulsion.

5. Energy in Food

Page 47 — Application Question

Q1 a) Weigh a corn flake and skewer it on a mounted needle. Add a set volume of water to a boiling tube which is held by a clamp. Measure the temperature of the water with a thermometer. Set fire to the corn flake using a Bunsen burner flame. Immediately hold the burning corn flake under the boiling tube until it goes out. Relight the corn flake and hold it under the tube immediately. Repeat until the corn flake no longer catches fire. Measure the final temperature of the water and record the temperature change.

b) The corn flake and the piece of pasta might not have had the same initial mass, so the student may be comparing the energy contained in different masses of food. To make it a fair comparison, she could use the formula:

$$\text{Energy per gram of food (J/g)} = \frac{\text{energy in food (J)}}{\text{mass of food (g)}}$$

6. Transport in Cells

Page 51 — Fact Recall Questions

Q1 The net movement of water molecules across a partially permeable membrane from a region of higher water concentration to a region of lower water concentration. / The net movement of water molecules across a partially permeable membrane from a region of lower solute concentration to a region of higher solute concentration.

Q2 Cells can absorb ions from very dilute solutions using active transport. The energy transferred from respiration is used to move ions from an area of lower concentration to an area of higher concentration / against a concentration gradient.

Page 51 — Application Question

Q1 B

The glucose molecules move by diffusion from an area of higher concentration inside the cell to an area of lower concentration outside the cell.

7. Investigating Osmosis in Plant Cells

Page 54 — Application Question

Q1 a) i) The (mean) length of the potato cylinders.

The dependent variable is the variable you measure — in this case the length of the potato cylinders.

ii) The concentration of the sugar solution.

The independent variable is the variable you change.

b) Any two from: e.g. the volume of the sucrose solutions / the age/type of potatoes used / the length of time the potato cylinders are left for.

c)
$$\text{percentage change in length} = \frac{\text{final length} - \text{initial length}}{\text{initial length}} \times 100$$
$$= \frac{8.5 - 9.6}{9.6} \times 100 = \mathbf{-11.5\%} \text{ (3 s.f.)}$$

Pages 56-57 — Biological Molecules and Transport in Cells Exam-style Questions

1 a) Benedict's reagent ***(1 mark)***

b) That glucose is not present in the sample ***(1 mark)***.

c) Iodine solution ***(1 mark)***. If the sample contained starch, the solution would have changed from a browny-orange ***(1 mark)*** to blue-black ***(1 mark)***.

2 a) Because every enzyme has an active site with a unique shape that usually only fits the substrate involved in a single reaction ***(1 mark)***. If the substrate doesn't match the enzyme's active site, then the reaction won't be catalysed ***(1 mark)***.

b) Line A. The line for A shows a faster rate than the line for B ***(1 mark)***. Higher temperatures increase the rate of a reaction, so line A must represent the experiment at the higher temperature of 25 °C ***(1 mark)***.

c) Increasing the temperature to 50 °C caused the shape of enzyme X's active site to change / denatured the enzyme ***(1 mark)***, so the enzyme could no longer catalyse the reaction ***(1 mark)***.

3 The photograph shows that in the test tubes with hydrochloric acid only and pepsin only (test tubes 1 and 2), the meat hasn't been fully digested ***(1 mark)***. However, in the test tube with both pepsin and hydrochloric acid (test tube 3) the meat sample has been completely digested ***(1 mark)***. This suggests that pepsin requires acidic conditions/low pH to function at its best ***(1 mark)***.

4 a) Water moves by osmosis from a region of higher water concentration to region of a lower water concentration ***(1 mark)***. The potato has a lower water concentration than the water in the dish, so water moves from the dish into the potato cells ***(1 mark)***. The potato has a higher water concentration than the sugar/well, so water moves from the potato into the well and dissolves the sugar/creates a sugar solution ***(1 mark)***.

b) There's no sugar in the well in the potato in experiment B, so no water is drawn out of the potato into the well at the top ***(1 mark)***. This means the difference in the concentration of the solution in the potato cells and in the dish is smaller ***(1 mark)***, so the movement of water molecules by osmosis is reduced ***(1 mark)***.

Topic 2 — Cells and Control

Topic 2a — Cell Division and Stem Cells

1. Mitosis

Page 61 — Fact Recall Questions

Q1 The DNA is copied and forms X-shaped chromosomes. (Each 'arm' of the chromosome is an exact duplicate of the other.)

Q2 Spindle fibres pull the chromosomes apart and the chromatids are pulled to opposite ends of the cell.

Q3 cytokinesis

Q4 Any two from: e.g. growth / replacing damaged cells / asexual reproduction.

Page 61 — Application Questions

Q1 a) genetically identical

b) two

If a cell has two sets of chromosomes it means that it will have two copies of each chromosome.

c) Membranes are forming around each of the sets of chromosomes, forming the nuclei of the two new cells. The cell membrane and cytoplasm are dividing.

This photograph is showing the final stage of mitosis (telophase). Cytokinesis (division of the cytoplasm) happens alongside telophase.

Q2 number of cells = 2^{10}

$= 2 \times 2 \times 2 \times 2 \times 2 \times 2 \times 2 \times 2 \times 2 \times 2 = \mathbf{1024}$

2. Cell Division and Growth

Page 63 — Fact Recall Questions

Q1 Cell differentiation is the process by which a cell changes to become specialised for its job.

Q2 A change in one of the genes that controls cell division can cause the cell to start dividing uncontrollably. This can result in a mass of abnormal cells called a tumour. If the tumour invades and destroys surrounding tissue, it's a cancer.

Page 63 — Application Question

Q1 60%

3. Stem Cells

Page 66 — Fact Recall Questions

Q1 An undifferentiated cell that has the potential to differentiate into different types of cell.

Q2 Early embryonic stem cells can divide and produce any type of cell at all. Adult stem cells can only produce certain types of cells.

Q3 Any two from: e.g. the transplanted cells may form a tumour if they divide too fast. / The transplanted cells could be carrying a virus that would then be passed on to the patient. / The transplanted cells may be rejected by the patient's body.

Q4 meristem

Page 66 — Application Questions

Q1 E.g. to replace damaged skin cells / repair the skin at the site of a wound.

Q2 a) Stem cells could be made to differentiate into neurones, which could replace the damaged/dead neurones.

b) E.g. producing nerve cells to replace damaged tissue in people with paralysis. / Producing insulin-producing cells for people with diabetes.

Q3 E.g. because the embryos left over from fertility clinics will be destroyed anyway if they are not used for fertility treatment, so it's better to use these rather than creating new embryos to use in research.

Page 68 — Cell Division and Stem Cells
Exam-style Questions

1 a) chromosome ***(1 mark)***

b) D ***(1 mark)***

c) 3 ***(1 mark)*** e.g. because it shows the membrane around the nucleus breaking down / the chromosomes have condensed but are still in the nucleus ***(1 mark)***.

d) Mitosis produces two new daughter cells ***(1 mark)***. The daughter cells are diploid ***(1 mark)*** and are genetically identical to each other and the parent cell ***(1 mark)***.

2 a) 2nd percentile ***(1 mark)***

b) 7.9 kg (accept answers between 7.8 and 8.0 kg) ***(1 mark)***

c) E.g. It is used to assess a child's growth over time ***(1 mark)***, so that an overall pattern in development can be seen / any problems can be spotted ***(1 mark)***.

Topic 2b — Nervous Control

1. The Nervous System

Page 71 — Fact Recall Questions

Q1 It carries impulses away from the cell body.

Q2 To speed up nervous impulses.

Page 71 — Application Question

Q1 a) i) The stimulus is the sound of the cat moving. It will be detected by (sound) receptors in the dog's ears.

ii) sensory neurone

b) i) motor neurone

ii) They will contract.

2. Synapses and Reflexes

Page 74 — Fact Recall Questions

Q1 Neurotransmitters diffuse across the gap between the two neurones, which sets off an electrical impulse in the next neurone.

Q2 A reflex is a fast, automatic response to a stimulus.

Q3 No

Reflexes are automatic — you don't have to think about them, so they don't pass through conscious parts of the brain.

Q4 a relay neurone

Q5 The gland will secrete a hormone.

Page 74 — Application Question

Q1 a) The sharp point of the drawing pin.

b) A muscle in the leg. It contracts, moving the foot away from the source of the pain (the pin).

c) Stimulus → Receptor → Sensory neurone → Relay neurone → Motor neurone → Effector/Muscle → Response

3. The Brain

Page 77 — Fact Recall Questions

Q1 cerebrum

Q2 at the back of the brain

Q3 E.g. CT scan, PET scan.

Q4 E.g. scientists haven't found a way to repair nervous tissue and it doesn't readily repair itself. Some parts of the nervous system are hard to access. Treatment may cause further damage.

Page 77 — Application Questions

Q1 medulla oblongata

Q2 the cerebellum

For questions like this, you need to look at the information to see what the symptoms are. You can then link the symptoms to which skill is being affected (in this case muscle coordination), and then link the skill to the part of the brain responsible for it.

4. The Eye

Page 80 — Fact Recall Questions

Q1 cornea, lens

Q2 To detect light. / Rods detect light intensity. Cones detect colour.

Q3 A cloudy patch on the lens (which stops light from being able to enter the eye normally).

Page 80 — Application Question

Q1 The glasses have a concave lens which refracts the light so that the rays focus on the retina, rather than in front of it. This produces a clearer image.

Pages 82-83 — Nervous Control
Exam-style Questions

1 a) In the skin on the subject's fingertip ***(1 mark)***.

b) sensory neurone ***(1 mark)***

c) It would get faster ***(1 mark)***. The presence of the drug increases the amount of neurotransmitter released at the synapses, so it would take less time for an impulse to be triggered in the next neurone ***(1 mark)***.

d) E.g. reflexes are fast ***(1 mark)***, so we quickly respond to danger, decreasing our chances of injury ***(1 mark)***. Reflexes are automatic ***(1 mark)***, so we don't have to waste time thinking about our response, which reduces our chance of injury ***(1 mark)***.

2 a) the cerebrum ***(1 mark)***

b) E.g. they could carry out a CT scan ***(1 mark)***.

3 a) Light receptors in the eye / on the retina detect the stimulus of a star appearing on the screen ***(1 mark)***. Electrical impulses are sent from the receptors to the brain along a sensory neurone / the optic nerve ***(1 mark)***.

b) before exercise: 4 + 7 = 11 people ***(1 mark)***
after exercise: 4 + 9 + 6 = 19 people ***(1 mark)***
19 – 11 = 8 people
So 8 more people had a reaction time of less than 0.3 s after exercise than before exercise ***(1 mark)***.

c) E.g. the reaction times of the group of participants after exercise were generally faster than their reaction times before exercise ***(1 mark)***.

Topic 3 — Genetics

Topic 3a — Reproduction, DNA and Protein Synthesis

1. Sexual Reproduction and Meiosis

Page 86 — Fact Recall Questions

Q1 one
Q2 In the reproductive organs.
Q3 two
Q4 four
Q5 False
The chromosomes from the mother and father are mixed during the first division of meiosis, then each gamete only gets half of the chromosomes during the second division.

Page 86 — Application Questions

Q1 a) 39
b) 38
c) 32
Q2 Before the first division, the cell duplicates its DNA. So when the first division happens, cells will have one full set of chromosomes again.
Duplicating the DNA creates X-shaped chromosomes, where each 'arm' of the chromosome has the same DNA.

2. Asexual and Sexual Reproduction

Page 88 — Application Question

Q1 a) The sexually reproducing species is more likely to survive the climate change. This is because a sexually reproducing species has greater genetic variation than an asexually reproducing species. This means a sexually reproducing population is more likely to have individuals with characteristics that will help them to survive and reproduce in the new environment.
b) The asexually reproducing species, because its reproductive cycle is likely to be shorter than that of the sexually reproducing species, so it will produce more offspring more quickly.

3. DNA

Page 92 — Fact Recall Questions

Q1 Two strands of DNA twisted together in a double helix shape/double stranded spiral.
Q2 a) gene
b) genome
Q3 a) A sugar, a phosphate group and one base.
b) The sugars and phosphate groups.
Q4 (weak) hydrogen bonds

Page 92 — Application Questions

Q1 A G A T G C T T A C T T
In DNA, A always pairs with T, and C always pairs with G.
Q2 a) The washing-up liquid is a detergent. It will break down the cell membranes of the kiwi cells so that the DNA is released.
b) salt
c) A stringy white precipitate/solid.

4. Protein Synthesis

Page 94 — Application Questions

Q1 serine, threonine, asparagine, glutamic acid
Q2 E.g. a mutation in the gene that codes for the enzyme that converts phenylalanine into tyrosine could change the enzyme's amino acid sequence. This could alter the specific shape of the enzyme and therefore its activity, preventing it from being able to carry out its function.

5. More on Protein Synthesis

Page 97 — Fact Recall Questions

Q1 mRNA carries the code found in genes/DNA from the cell nucleus to the ribosomes in the cytoplasm.
Q2 RNA polymerase
Q3 tRNA brings amino acids to the ribosome for assembly into a protein.
Q4 A sequence of three bases in mRNA that codes for an amino acid.
Q5 ribosome

Page 97 — Application Questions

Q1 A U C G G A U U U A C U
A in DNA always pairs with U in mRNA.
Q2 A mutation in the non-coding DNA at the start of the gene could prevent RNA polymerase from binding. This would prevent the gene from being transcribed and stop the protein it codes for being made. The gene would be "switched off".

Pages 99-100 — Reproduction, DNA and Protein Synthesis Exam-style Questions

1 a) Sexual, because it involves the joining of male and female gametes / it involves two parents ***(1 mark)***.
b) E.g. it produces variation in the offspring ***(1 mark)***. This increases the chance of the species surviving a change in the environment because it's likely that variation will have led to some of the offspring being able to survive in the new environment ***(1 mark)***. The individuals that have a better chance of survival are more likely to breed successfully ***(1 mark)*** and pass the genes for the characteristics on ***(1 mark)***.
c) They have received genetic material/chromosomes from both the male pig and the female pig ***(1 mark)*** and it is this genetic material/the chromosomes that control the offspring's characteristics ***(1 mark)***.
d) So that when two gametes join at fertilisation, the full number of chromosomes is reached (two copies of each) ***(1 mark)***.
e) mitosis ***(1 mark)***

2 a) None of the base pairs that contain adenine contain cytosine (A always pairs with T).
So $100 - 46 = 54\%$ of the base pairs contain cytosine.
54% of $2.16 \times 10^6 = ((2.16 \times 10^6) \div 100) \times 54$
$=$ **1 166 400**
(2 marks for the correct answer, otherwise 1 mark for showing that cytosine is in 54% of the base pairs)

This question is marked as higher only because it involves a calculation using standard form (which is a higher only maths requirement).

b) phosphate group ***(1 mark)***, sugar ***(1 mark)***

c) E.g. by adding ice-cold alcohol to the solution ***(1 mark)***.

3 a) 12 ***(1 mark)***

A codon is a base triplet (a sequence of 3 bases). 3 bases code for each amino acid, so 3 × 4 = 12 bases code for this amino acid sequence.

b) The mRNA would attach to a ribosome ***(1 mark)***. Amino acids would be brought to the ribosome by tRNA ***(1 mark)***. Anticodons on the tRNA pair up with complementary codons in the mRNA to ensure that amino acids are brought to the ribosome in the correct order ***(1 mark)***. The ribosome would then join the amino acids together ***(1 mark)***.

4 The genetic variant may code for a different sequence of amino acids ***(1 mark)***, which may change the shape of the protein being coded for ***(1 mark)***. This could alter the protein's activity ***(1 mark)***, which could end up altering the fly's wing shape, to give it curly wings ***(1 mark)***.

Topic 3b — Genetic Diagrams and Inheritance

1. Genes and Alleles

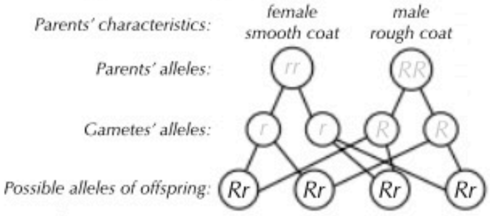
Page 101 — Fact Recall Question

Q1 a) Different versions of the same gene.
b) When an organism has two alleles for a particular gene that are the same.
c) The allele for the characteristic that's shown even if two different alleles for the same gene are present.
d) The characteristics you have.

2. Genetic Diagrams and Family Pedigrees

Page 107 — Application Questions

Q1 a)



b) a rough coat

Q2 a) Because there are no carriers of the disorder.
b) a purple circle
c) i) dd
ii) Dd

You know from the diagram that Kate has polydactyly, so she must have at least one copy of the dominant allele 'D'. You also know that she doesn't have two copies of the dominant allele, as her father Clark doesn't have polydactyly, so she couldn't have inherited a second 'D' allele from him. Therefore her genotype must be Dd.

d) *Kate's alleles*

D	*d*	
Dd	*dd*	*d*
Dd	*dd*	*d*

Aden's alleles

Probability of new baby having polydactyly = 0.5 or 50% or 1:1 or 1 in 2 or ½

3. The Work of Mendel

Page 110 — Fact Recall Questions

Q1 false

Mendel found that the hereditary units are passed on unchanged from parents to offspring.

Q2 No one knew about genes, DNA or chromosomes when Mendel was still alive, so the significance of his work wasn't realised until after he had died.

These days people recognise Mendel as one of the founding fathers of genetics. He was just a bit ahead of his time. Poor Mendel.

Page 110 — Application Question

Q1

Seed colour of pea plant	Type of hereditary unit		
	Just green	Just yellow	Both green and yellow
Green	✓	✗	✗
Yellow	✗	✓	✓

The yellow hereditary unit is dominant, so if the pea plant has both yellow and green hereditary units its seeds will be yellow. If the plant just has yellow hereditary units its seeds will also be yellow. For its seeds to be green, the plant has to have two of the green hereditary units.

4. Sex Determination and Sex-linked Disorders

Page 114 — Fact Recall Questions

Q1 one

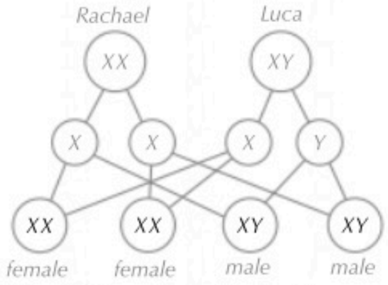
Q2 false

Half carry X chromosomes, and half carry Y chromosomes.

Q3 Sex-linked disorders are usually due to a faulty allele on the X chromosome. Women need two copies of the recessive allele to have an X-linked recessive disorder, while men only need one copy.

Page 114 — Application Questions

Q1



Q2 0.5 or 50% or 1:1 or 1 in 2 or ½.

Q3 *Rachael's gametes*

	X	*X*
X	*XX*	*XX*
Y	*XY*	*XY*

Luca's gametes

Q4 The son will not have haemophilia. As a boy, he will only inherit one X chromosome and therefore one allele. As his X chromosome will come from his mother (Rachael) who is unaffected and not a carrier of the disease, he will not inherit a faulty allele and will not have the disease.

5. Inheritance of Blood Groups

Page 116 — Fact Recall Questions

Q1 There are more than two different versions of the gene.

Q2 Two alleles of a gene are expressed in the same phenotype.

Q3 I^O

Page 116 — Application Questions

Q1 C

Q2 50% / ½ / 0.5

6. Variation

Page 119 — Fact Recall Questions

Q1 False

Variation within a population can also be caused by environmental conditions.

Q2 a) A change to the sequence of bases in DNA.

b) Most mutations have no effect on the protein the gene codes for, so most mutations have no effect on the organism's phenotype.

Page 119 — Application Questions

Q1 a) both

b) environment only

Q2 The results from Study 1 suggest that genes must influence IQ because identical twins have the same genes and non-identical twins have different genes. The results from Study 2 suggest that environment also influences IQ. This is because identical twins have exactly the same genes, which means that differences in their IQs must be down to differences in their environment/the way they were brought up.

7. The Human Genome Project

Page 121 — Application Questions

Q1 E.g. Sarah can get tailored advice on lifestyle factors to reduce the likelihood of developing breast cancer / doctors may be able to prescribe a more effective drug for her if she develops breast cancer / she can have regular checks to ensure early treatment if she develops breast cancer.

Q2 Any two from: e.g. Sarah could be discriminated against by life insurers / she could be discriminated against by employers / she could be put under pressure not to have children so that the gene is not passed on / she could have increased stress levels from worrying about potentially developing breast cancer.

Pages 123-124 — Genetic Diagrams and Inheritance Exam-style Questions

1 a) HH or Hh ***(1 mark)***

b) A ***(1 mark)***

c) *mother's alleles*

	H	*h*
H	*HH*	*Hh*
h	*Hh*	*hh*

father's alleles

HH and Hh offspring have Huntington's disease. So the probability is 3 in 4 or **75%**.
(1 mark for a correct Punnett square, plus 1 mark for 75%.)

2 a) They have both inherited the same alleles for hair colour from their parents, but different alleles for eye colour ***(1 mark)***. This genetic variation is the result of alleles being combined in different ways during sexual reproduction ***(1 mark)***.

b) E.g. how often they train / how hard they train / how well they are coached / how good the facilities they train at are / how good their diet is ***(1 mark)***.

You're not expected to know the answer to this question, just to make sensible suggestions.

c) Males only have one X chromosome which they receive from their mother ***(1 mark)***. Dave does not have the disorder so he must have inherited a normal colour vision allele from his mother ***(1 mark)***. A female must carry two faulty alleles to have colour blindness ***(1 mark)***. Since their mother has one normal allele, she is not colour blind ***(1 mark)***.

3 a) 0.5 / 50% / 1 in 2 / ½ chance ***(1 mark)***

b) E.g.

Kaye's alleles

	D	*d*
d	*Dd*	*dd*
d	*Dd*	*dd*

Mark's alleles

Kaye and Mark are likely to have a 50:50 / 1:1 ratio of dimpled to undimpled offspring.
(1 mark for correct a Punnett square, plus 1 mark for a correct ratio.)

c) The genotype for type O blood is I^OI^O, so the baby must have inherited one I^O allele from each parent. ***(1 mark)***. The genotype for type AB blood is I^AI^B, so if either Mark or Kaye has type AB blood, it would have been impossible for the baby to have inherited two I^O alleles ***(1 mark)***.

4 a) Homozygous, because he has a recessive disorder / cystic fibrosis ***(1 mark)***.

There are carriers in the family tree, so cystic fibrosis must be a recessive disorder.

b) Ff ***(1 mark)***. For a child to have cystic fibrosis, both parents must carry the cystic fibrosis allele ***(1 mark)***.

Tony is a carrier so his alleles must be Ff. As their child has cystic fibrosis (ff) it must have inherited a cystic fibrosis allele from both Tony and Bex, as it's a recessive disorder. Bex doesn't have cystic fibrosis, so she must be a carrier (Ff).

c) E.g. *Ivana's alleles*

f	*f*	
Ff	*Ff*	*F*
Ff	*Ff*	*F*

Tam's alleles

No, because to have cystic fibrosis you need the genotype ff. None of the offspring are ff. / Tam is FF so all his offspring must inherit one healthy allele.
(1 mark for a correct Punnett square, plus 1 mark for a correct conclusion.)

Topic 4 — Natural Selection and Genetic Modification

Topic 4a — Natural Selection and Evolution

1. Natural Selection and Evidence for Evolution

Page 126 — Fact Recall Questions

Q1 Through mutation.

Q2 Something that affects an organism's chance of surviving and reproducing.

Q3 False

Organisms that are better adapted to the selection pressures in their environment are better able to compete.

Page 127 — Application Questions

Q1 E.g. the weeds in a population show variation — some are resistant to glyphosate, others aren't / a new allele arises (due to a mutation) which makes some weeds resistant to glyphosate. The glyphosate-resistant weeds are better suited to an environment where glyphosate-containing weedkillers (a selection pressure) are used, so they are more likely to survive and reproduce than weeds that aren't glyphosate-resistant. This means that the allele for glyphosate resistance is more likely to be passed on to the next generation, making glyphosate resistance more common in the population.

You could get asked to explain the selection of pretty much any characteristic in the exam — make sure you can apply the key points of Darwin's theory to any context.

Q2 a) By around 3.5 – 2.1 = **1.4 cm**
(accept any answer between 1.3 and 1.5 cm).

b) E.g. the reindeer population in 1810 would have shown variation — some would have had shorter fur and some longer fur (due to a mix of alleles in the population). The temperature of the new environment would have acted as a selection pressure. Reindeer with shorter fur would have been better suited to the new, warmer environment (as they would have been less likely to overheat), so they would have been more likely to survive and breed successfully than the reindeer with long fur. This meant that the allele for short fur was more likely to be passed on to the next generation. This allele became more common in the population, eventually reducing the average fur length.

2. Darwin and Wallace

Page 129 — Fact Recall Questions

Q1 Darwin spent 5 years on a voyage round the world studying plants and animals. Whilst on the voyage, he noticed that there was variation in members of the same species and that those with characteristics most suited to the environment were more likely to survive. He also noticed that characteristics could be passed on to offspring.

Q2 E.g. that characteristics are passed on from parents to offspring via their genes/DNA/alleles. / That individuals in a population show variation in their characteristics because of differences in their genes/DNA/alleles. / That new alleles arise through mutations in DNA.

Q3 He came up with the idea of natural selection independently of Darwin and published papers on it. His observations provided evidence to help support the theory, e.g. he realised that warning colours used to deter predators are an example of a beneficial characteristic that evolved by natural selection.

Q4 Research into any two from: e.g. classification of organisms / antibiotic resistance / conservation.

3. Evidence for Human Evolution — Fossils

Page 132 — Fact Recall Questions

Q1 They have characteristics in between apes and humans. When arranged in chronological order, they show how hominids gradually became less ape-like and more human-like.

Q2 False

Ardi is older than Lucy by 1.2 million years.

Q3 "Turkana Boy" is a 1.6 million year old fossil skeleton of the species *Homo erectus*. He has a mixture of human and ape-like features, but is more human-like than older hominid fossils.

Page 132 — Application Questions

Q1 A = Lucy, B = Ardi, C = Turkana Boy

Q2 B (Ardi), A (Lucy), C (Turkana Boy)

Q3 You would expect the fossil to have shorter arms and longer legs than Lucy.

As the fossil is more recent than Lucy, you would expect it to have features that are more like a modern human.

4. Evidence for Human Evolution — Stone Tools

Page 134 — Application Question

Q1 a) C, A, B

b) C is the least sculpted, least complex tool, so it is likely to be the oldest. B is the most sculpted, most complex tool, so it is likely to be the most recent. A is somewhere in between the two.

c) B

B is the most complex, most recent tool, so it's most likely to have been made by a Homo sapiens (modern human).

d) Supports the answer — newer layers of rock tend to be found above older layers of rock. C is a more recent tool than A and more recently made tools are more likely to be found in newer layers of rock.

5. The Pentadactyl Limb

Page 135 — Application Question

Q1 Because they have a similar bone structure. If the bird and the whale had evolved from different ancestors, it'd be highly unlikely that they'd share a similar bone structure.

6. Classification

Page 137 — Fact Recall Questions

Q1 C

Q2 Differences in RNA sequences suggested that some members of the Prokaryote kingdom (used in the five kingdom classification method) were not as closely related as first thought. So it was suggested that this kingdom should be split into two groups, which became two of the domains in the three domain classification system.

Q3 Archaea, Bacteria and Eukarya

Page 139 — Natural Selection and Evolution Exam-style Questions

1 a) E.g. they could have used stratigraphy/looked at the depth of the rock layer the tool was found in. / They could have used radiometric dating to date the layer of rock that the tool was found in. ***(1 mark)***

b) i) C ***(1 mark)***

You should remember that Lucy is 3.2 million years old. The tool is 1.5 million years old. 3.2 – 1.5 = 1.7.

ii) The tool is too complex ***(1 mark)*** and Lucy had not evolved enough to have a brain large enough to make/use it ***(1 mark)***.

2 a) How to grade your answer:

Level 0: There is no relevant information. ***(No marks)***

Level 1: There is some information about natural selection. The points made are basic and not linked together. ***(1 to 2 marks)***

Level 2: There is some explanation of how the milk snake may have evolved via natural selection to have a similar colouring to the coral snake. Some of the points made are linked together. ***(3 to 4 marks)***

Level 3: There is a clear and detailed explanation of how the milk snake may have evolved via natural selection to have a similar colouring to the coral snake. The points made are well-linked and the answer has a clear and logical structure. ***(5 to 6 marks)***

Here are some points your answer may include:

The original milk snake population showed variation — some had similar colouring to the coral snake, others didn't. / A mutation produced an allele, which caused some milk snakes to have similar colouring to the coral snake.
Predation is a selection pressure.
Milk snakes that looked like the coral snake were less likely to be eaten by predators and so more likely to survive and reproduce, than milk snakes that didn't look like coral snakes.
This means that the allele that causes coral snake colouring was more likely to be passed on to the next generation of milk snakes.
This is how it spread and became more common in the population.

b) E.g. (Alfred Russel) Wallace ***(1 mark)***

Topic 4b — Genetic Modification

1. Selective Breeding

Page 141 — Fact Recall Questions

Q1 From your existing stock, select the ones which have the characteristics you want. (Individuals will have different characteristics due to genetic variation.) Breed your chosen individuals together. Select the best of the offspring and breed them together. Continue for several generations.

Q2 E.g. it can lead to inbreeding. This can cause health problems because there's more chance of organisms inheriting harmful genetic defects when the gene pool is limited. / If a new disease appears, there's less chance of resistance alleles being present, making it more likely that the whole population will be wiped out by the disease.

2. Tissue Culture

Page 143 — Fact Recall Question

Q1 Tissue culture is when cells are grown on or in an artificial growth medium.

Page 143 — Application Questions

Q1 a) E.g. the scientist could remove several small pieces of tissue from the root or shoot tips of one of the existing orchid plants. They could then grow the tissue under aseptic conditions on a growth medium containing nutrients and growth hormones. Once the tissues produce shoots and roots they could be moved to potting compost to carry on growing.

b) E.g. because new orchids can be grown quickly/ in very little space/can be grown all year round. / Because lots of plants can be grown from one (parent) plant. / Because there aren't enough orchids for normal breeding methods.

Q2 E.g. because they want to be able to study the effects of the vaccine on animal cells in isolation. / Because they want lots of identical cells to test the vaccines on, so that it is a fair test.

3. Genetic Engineering

Page 146 — Fact Recall Questions

Q1 The transfer of a gene from one organism's genome to another organism's genome in order to introduce a desirable characteristic.

Q2 a) To recognise specific sequences of DNA and cut the DNA at these points. / To cut out the desired gene and cut open the vector DNA.

b) To join two pieces of DNA together (via their sticky ends).

c) To transfer DNA into a cell.

Page 146 — Application Question

Q1 a) Any two from: e.g. the corn-based vaccine may be cheaper than the normal vaccine to transport and store because it does not need refrigerating. This may be particularly important in developing countries that don't have a lot of money to spend on healthcare. / The corn-based vaccine may be easier to safely administer than the normal vaccine, because it avoids the use of needles, which need sterilising. This might be particularly beneficial in developing countries where healthcare facilities might be limited. / The corn-based vaccine may increase uptake of the vaccine because it avoids the use of needles, which some people may not like. This might be particularly important in areas where hepatitis B is common.

Any sensible suggestion that links back to the information given in the question would be fine here.

b) E.g. the transplanted gene that enables the corn to produce the vaccine may get out into the environment and be picked up by wild plants. / The GM corn might adversely affect food chains/ human health.

4. Human Population Growth and GM organisms

Page 149 — Application Questions

Q1 a) biological control

b) E.g. the ladybirds could end up becoming a pest themselves. / They might fly away/leave the area where the fruit is grown.

Q2 a) E.g. excess fertilisers can run off into nearby lakes/rivers, causing eutrophication/an excess of nutrients in the water, leading to algal blooms and the death of organisms living in the water.

b) E.g. the GM crop may be more expensive than the fertiliser. / The farmer might not want to become dependent on the biotechnology firm. / The farmer might be concerned about the long-term effects of GM crops on human health/the environment.

Q3 a) E.g. if insects ate the potato, they'd be poisoned by the protein. If less of the crop was eaten by insects, this could improve crop yield. / This could decrease the need to use chemical pesticides.

b) E.g. the insects that feed on the potato plants could develop resistance to the Bt protein and no longer be killed by it.

Page 151 — Genetic Modification

Exam-style Questions

1 C *(1 mark)*

2 a) i) E.g. it means more of his wheat crop will survive/the wheat crop is less likely to get damaged by the disease so the wheat yield will increase ***(1 mark)***.

ii) E.g. it may be cheaper ***(1 mark)*** because the farmer can selectively breed the wheat himself, rather than paying a scientist/technology company to do it ***(1 mark)***.

You get one mark here for coming up with any sensible advantage to the farmer of using selective breeding and one mark for explaining it.

b) When exposed to the disease, some of the farmer's wheat plants will be resistant to it ***(1 mark)***. The farmer should select these resistant plants and breed them together ***(1 mark)***. He should then select the most disease-resistant offspring and breed them together ***(1 mark)***. After several generations of doing this, all/most of the wheat plants will be disease-resistant ***(1 mark)***.

c) E.g. the gene pool would be reduced, so there's less chance of alleles for resistance for a new disease being present ***(1 mark)***. This means that if a new disease appears, all the farmer's wheat plants are likely to be wiped out ***(1 mark)***.

3 a) E.g. the human gene for factor VIII could be cut out using restriction enzymes ***(1 mark)***. The same restriction enzymes could be used to cut open the DNA of a vector ***(1 mark)***. The factor VIII gene could then be joined to the vector DNA using ligase ***(1 mark)***. The recombinant DNA/vector containing the factor VIII gene could then be inserted into the animal cells, which can then produce the human factor VIII protein ***(1 mark)***.

b) E.g. it avoids the creation of genetically modified embryos that do not survive. / It avoids creating genetically modified animals that may suffer from health problems. / It is easier/faster and cheaper to grow cells than it is to rear whole animals. ***(1 mark)***

c) E.g. the cells containing the factor VIII gene could be separated from each other using enzymes ***(1 mark)***. The separated cells could then be placed in a culture vessel containing a growth medium with the nutrients they need to grow and multiply ***(1 mark)***. After several rounds of cell division, the cells could be split into separate vessels to encourage further growth ***(1 mark)***.

Topic 5 — Health, Disease and the Development of Medicines

Topic 5a — Health and Disease

1. Introduction to Health and Disease

Page 152 — Fact Recall Questions

Q1 Health is a state of complete physical, mental and social well-being.

Q2 Communicable diseases can be spread between individuals, whereas non-communicable diseases cannot.

2. Communicable Diseases

Page 157 — Fact Recall Questions

Q1 a) E.g. coughing and lung damage.

b) The pathogen is spread through the air in droplets produced when people infected with tuberculosis cough and sneeze.

Q2 E.g. it can be reduced by making sure that people have access to clean water.

Q3 E.g. they will have stomach pain and nausea. They may also exhibit vomiting.

Q4 a) ash trees

b) E.g. leaf loss and bark lesions.

Q5 Mosquito nets can prevent people from being bitten by mosquitoes when they're asleep, meaning that the protist that causes malaria isn't passed on.

Q6 An infection that is spread through sexual contact, such as genital contact and sexual intercourse.

Q7 E.g. by wearing a condom during sex or avoiding sexual contact.

Q8 HIV kills white blood cells. Eventually, the immune system of the infected individual becomes so weak that it fails. This makes the body much more susceptible to other diseases.

Page 157 — Application Questions

Q1 Ebola is spread through contact with bodily fluids of an infected person. Putting the patient in isolation helps to prevent others from coming into contact with infected fluids which minimises the spread of the disease.

Q2 The nurse may come into contact with pathogens for many diseases. By washing his hands, this will prevent pathogens being passed on to other people that he comes into contact with.

3. Virus Reproduction

Page 159 — Fact Recall Questions

Q1 The virus attaches itself to a host cell and injects its genetic material into the cell. The virus forces the host cells to replicate its genetic material and make the components of new viruses using the proteins and enzymes already present in the cell. The components then assemble to make new viruses which can burst out of the host cell, and infect further cells.

Q2 A trigger causes the viral genetic material to be released from the genome of the host cell.

Page 159 — Application Question

Q1 lytic pathway

4. Plant Diseases

Page 161 — Fact Recall Questions

Q1 E.g. a waxy cuticle on leaves and stems provides a barrier to stop pathogens entering the plant. The cuticle may also reduce the build up of water, which could contain pathogens, on the leaf. Plant cells are surrounded by a cell wall, which helps to prevent pathogens from entering the cell.

Q2 E.g. diseased plants are normally detected by observations. Most plants show visual symptoms of disease.

Page 161 — Application Question

Q1 a) E.g. the plant pathologist could add nitrogen to the soil and observe any changes to the leaf colour. If the symptoms improve then they were likely caused by a nitrogen deficiency.

b) E.g. the plant pathologist could use monoclonal antibodies in the lab to detect antigens unique to the fungus in the plant tissue. / The plant pathologist could use techniques which allow detection of small amounts of fungal DNA in the plant tissue to see if the fungus is present.

Page 163 — Health and Disease Exam-style Questions

1 a) E.g. repeating episodes of fever / damage to red blood cells / damage to the liver ***(1 mark)***.

b) i) protist ***(1 mark)***

ii) Any two from: e.g. removing any containers that fill with rainwater. / Spraying exposed skin with insect repellant. / Sleeping under a mosquito net ***(1 mark for each correct answer)***.

c) The patient may be suffering from mental/social health issues, despite being disease free ***(1 mark)***.

2 a) i) E.g. some plants produce antiseptics which kill bacteria and fungi ***(1 mark)***. Some plants contain poisons which can deter pests from feeding on them ***(1 mark)***.

ii) E.g. they could be used as medicines ***(1 mark)***.

b) a fungus ***(1 mark)***

c) E.g. the pathogen/fungus may have been carried by the wind from other infected trees ***(1 mark)***.

3 a) i) The virus is spread through exchanging infected bodily fluids ***(1 mark)***.

ii) Any two from: e.g. by using a condom during sexual intercourse. / Taking medication which reduces the chance of the infection being passed on during sexual intercourse. / By drug users avoiding sharing needles.
(1 mark for each correct answer.)

b) i) host cell ***(1 mark)***

ii) In the lysogenic pathway, viral genetic material is taken up by the genome of the host cell ***(1 mark)***. The viral genetic material will be replicated whenever the cell divides ***(1 mark)***. The virus remains inactive until a trigger causes the viral genetic material to enter the lytic pathway ***(1 mark)***.

Topic 5b — Fighting Disease

1. Defences Against Disease

Page 165 — Fact Recall Questions

Q1 E.g. the skin, mucus and cilia.

Q2 E.g. they engulf pathogens using phagocytosis. They produce antibodies.

Page 165 — Application Question

Q1 E.g. hairs and mucus in your nose trap particles that could contain the SARS-CoV. / The trachea and bronchi secrete mucus to trap the SARS-CoV. / The trachea and bronchi are lined with cilia. These waft mucus containing the SARS-CoV up to the back of the throat where it can be swallowed.

2. Memory Lymphocytes and Immunisation

Page 167 — Application Questions

Q1 E.g. the vaccination will involve injecting a small amount of dead or inactive whooping cough pathogen. The pathogen will carry antigens which will trigger the B-lymphocytes to produce antibodies to target the pathogen. It will also trigger the production of memory lymphocytes which 'remember' the antigen. If the vaccinated person is infected with the whooping cough pathogen at a later date, the memory lymphocytes should be able to rapidly mass-produce antibodies to kill off the pathogen.

Q2 Following the first exposure to the chickenpox virus, memory lymphocytes were produced that were specific to an antigen on the chickenpox virus. When the child was exposed to the chickenpox virus again, the memory lymphocytes recognised the antigens and quickly mass-produced antibodies. The chickenpox virus was then removed by the immune system before symptoms were able to develop.

3. Pros and Cons of Immunisation

Page 168 — Application Question

Q1 If a large percentage of the population are immunised it means that the people who aren't immunised (i.e. very young babies) are less likely to catch the disease because there are fewer people to pass it on. This is known as herd immunity.

4. Monoclonal Antibodies

Page 169 — Fact Recall Questions

Q1 A mouse B-lymphocyte and a tumour/myeloma cell.

Q2 The hybridoma cells are cloned to get lots of identical cells that all produce the same antibodies (monoclonal antibodies). The antibodies are collected and purified.

5. Monoclonal Antibody Uses

Page 172 — Fact Recall Questions

Q1 a hormone / HCG

Q2 e.g. cancer

Page 173 — Application Questions

Q1 a) Monoclonal antibodies could be made which are specific to tumour markers present on the surface of the cancer cells. These monoclonal antibodies could be labelled with a radioactive element and given to the patient through a drip. Once they entered the blood, they would be transported around the body. If the monoclonal antibodies came into contact with a tumour marker, they would bind to it. A special camera that detects radioactivity could then be used to show the doctor any areas in the patients' body where cancer cells are located.

b) E.g. the monoclonal antibody drug specifically targets cancer cells so normal body cells are not killed, unlike radiotherapy which also affects normal body cells, leading to more side effects.

Q2 The blue beads are always carried in the flow of urine up the test stick. If the test has worked, the antibodies attached to the blue beads will bind to the antibodies in the control window, turning it blue.

6. Developing Drugs

Page 176 — Fact Recall Questions

Q1 Human cells, human tissues and live animals.

Q2 Any two from: e.g. to find out whether the drug works. / To find out about the drug's toxicity. / To find out the optimum/best dose of the drug.

Q3 a) healthy volunteers

b) It is very low.

Q4 A placebo is a substance that looks like the drug being tested but doesn't do anything.

Q5 A blind trial is a clinical trial where the patient does not know whether they are receiving the drug or the placebo. In a double-blind trial, neither the doctor nor the patients know who has been given the drug and who has been given the placebo, until the results of the trial have been gathered.

It's helpful to remember that 'double' means 'two' — so in a double-blind trial, there are two groups of people (doctors and patients) who don't know who receives the drug and who receives the placebo.

Pages 176-177 — Application Questions

Q1 a) E.g. a capsule without paracetamol.

b) E.g. an inhaler without steroids.

c) E.g. an injection without cortisone.

Q2 a) i) No, because it was a double-blind trial.

ii) E.g. a pill without any weight-loss drug.

b) E.g. Group 2 was included in the trial to make sure that the new drug, Drug Y, worked as well as/ better than other, similar weight-loss drugs already available on the market (like Drug Z). / To see how Drug Y compared to Drug Z.

c) E.g. that, on average, people taking Drug Y in this trial lost 4 lbs more than those taking the placebo, but 3 lbs less than those taking Drug Z.

7. Antibiotics

Page 178 — Fact Recall Questions

Q1 Antibiotics are drugs that kill or prevent the growth of bacteria.

Q2 Different antibiotics kill different types of bacteria.

Q3 Viruses aren't cells, they reproduce using a host organism's cells. Antibiotics selectively target bacterial cells, so antibiotics have no effect on the virus or the host cell.

8. Investigating Antibiotics and Antiseptics

Page 182 — Application Questions

Q1 Using the scale, 4 mm = 1 cm.

Antibiotic	Diameter (cm)	Radius (cm)	Area (cm^2)
A	13 ÷ 4 = **3.25**	1.625	$\pi \times (1.625)^2$ = 8.29... = **8**
B	4 ÷ 4 = **1**	0.5	$\pi \times (0.5)^2$ = 0.78... = **1**

Don't forget to halve the diameter to get the radius before calculating the area.

Q2 There would be no inhibition zone around the paper disc holding the antibiotic.

Q3 Out of the antibiotics tested, antibiotic A is the more effective antibiotic against the strain of bacteria used.

Pages 185-186 — Fighting Disease

Exam-style Questions

1 a) It produces hydrochloric acid which kills pathogens ***(1 mark)***.

b) The trachea and bronchi secrete mucus to trap pathogens ***(1 mark)***. They are also lined with cilia ***(1 mark)***. These waft the mucus up to the back of the throat where it can be swallowed ***(1 mark)***.

c) Lysozyme is an enzyme present in several secretions which kills bacteria ***(1 mark)***.

d) Antibodies only bind to specific antigens on the outside of specific pathogens ***(1 mark)***. These pathogens bound to antibodies can then be found by white blood cells and destroyed ***(1 mark)***.

2 a) In 1980, there were just over 4 million reported measles cases ***(1 mark)***. Between 1980 and 2014 the number of reported measles cases dropped to around 0.3 million (after rising to a peak of 4.5 million in around 1981) ***(1 mark)***. The estimated immunisation coverage was around 15% of the population in 1980 ***(1 mark)***. Between 1980 and 2014 it increased to around 85% ***(1 mark)***.

The question asks you to use data from the graph to support your answer — so you must include some figures to get the marks. The graph has three different axes, which can make things a bit tricky. Take your time and work out what each one shows before answering the question.

b) E.g. the data suggests that as the estimated percentage immunisation coverage increased, the number of reported measles cases decreased — this supports the case for immunising people against measles ***(1 mark)***. However it doesn't prove that the increase in immunisation coverage definitely caused the decrease in measles cases, since other factors may have been at work ***(1 mark)***. It also doesn't tell us anything about the side effects of immunisation ***(1 mark)***.

c) E.g. if a large enough percentage of the population are immunised against measles ***(1 mark)***, even the people who aren't immunised against the disease will be unlikely to catch it ***(1 mark)***, as there are fewer people able to pass it on ***(1 mark)***.

3 How to grade your answer:

Level 0: There is no relevant information. ***(No marks)***

Level 1: There is a brief explanation of how a pregnancy test works, but no information about the role of antibodies or HCG. ***(1 to 2 marks)***

Level 2: There is some explanation of how a pregnancy test works, including some information about the role of antibodies and HCG. ***(3 to 4 marks)***

Level 3: There is a clear and detailed explanation of how a pregnancy test works, including clear and detailed information about the role of antibodies and HCG. ***(5 to 6 marks)***

Here are some points your answer may include:
A hormone called HCG is present in the urine of women who are pregnant.
The woman urinates on the part of the pregnancy test stick that contains antibodies to HCG that are attached to blue beads.
The HCG present in the urine binds to the antibodies in this section.
The urine moves up the stick and carries the hormone and the beads with it.
The hormone binds to another set of antibodies to HCG on the test strip.
The test strip will turn blue as the HCG that's joined to the blue beads binds to the strip.
The urine continues up the stick to the control strip.
If the test has worked correctly, the control window (which contains an antibody to the antibody attached to the blue bead) should turn blue.
This is because the antibodies on the blue beads bind to the antibodies on the strip.

4 a) Using knowledge about how a particular disease works allows scientists to find molecules which could fight the disease ***(1 mark)***.

b) Because live animals have an intact small intestine and circulatory system ***(1 mark)***. Testing on just cells or tissues wouldn't show whether the drug has the desired effect on the absorption of nutrients from the small intestine to the bloodstream, because these body systems would not be intact ***(1 mark)***.

c) How to grade your answer:

Level 0: There is no relevant information. ***(No marks)***

Level 1: There is a brief explanation of what happens during a clinical trial, but no information about placebos or double-blind testing. ***(1 to 2 marks)***

Level 2: There is some explanation of what happens during a clinical trial, including some information about placebos or double-blind testing. ***(3 to 4 marks)***

Level 3: There is a clear and detailed explanation of what happens during a clinical trial, including clear and detailed information about placebos and double-blind testing. ***(5 to 6 marks)***

Here are some points your answer may include:
The drug is first tested on healthy volunteers. This is to make sure that it doesn't have any harmful side effects when the body is working normally.
A very low dose of the drug is given at first, and this is gradually increased.
If the results of the tests on healthy volunteers are good, the drug is tested on people suffering from the illness.
The optimum dose is found — this is the dose of drug that is the most effective and has few side effects.
To test how well the drug works, a placebo may be used. A placebo is a substance that looks like the drug being tested but doesn't do anything. Patients are randomly put into two groups — one is given the new drug, the other is given a placebo. This is so the doctor can see the actual difference the drug makes — it allows for the placebo effect.
Clinical trials are often double-blind — neither the doctor nor the patients in the study know who is getting the drug or the placebo. This is so the doctors monitoring the patients and analysing the results aren't subconsciously influenced by their knowledge.

5 a) Any two from: e.g. heat/sterilise the growth medium using an autoclave / use an autoclave to sterilise the Petri dish before using it / if an inoculating loop is used to transfer the bacterial sample to the Petri dish, sterilise the inoculating loop before using it, e.g. by passing it through a flame / keep the culture vial containing the sample covered with a lid as much as possible ***(2 marks)***.

b) Antibiotic 5 ***(1 mark)*** because this disc has the biggest inhibition zone around it ***(1 mark)***. This means that more bacteria were killed/unable to grow around antibiotic 5 than around any of the other antibiotics / the bacteria were least resistant to antibiotic 5 ***(1 mark)***.

It stands to reason that the best antibiotic for getting rid of the infection is the one that kills the most bacteria.

c) E.g. the size of the paper discs ***(1 mark)***, the concentration of the antibiotics ***(1 mark)***.
d) E.g. it shows that the lack of growth around the antibiotic discs is due to the effect of the antibiotics and not something else ***(1 mark)***.

Topic 5c — Non-Communicable Diseases

1. Risk Factors for Non-Communicable Diseases

Page 189 — Fact Recall Questions

Q1 Something linked to an increase in the likelihood that a person will develop a certain disease during their lifetime.
Q2 Any two from: e.g. smoking / drinking alcohol / diet / low levels of exercise.
Q3 E.g. cardiovascular disease, (lung) cancer.
Q4 E.g. obesity
Q5 E.g. they are costly because the National Health Service provides the resources for the treatment of patients all over the UK. / Sometimes, people suffering from a non-communicable disease may not be able to work. A reduction in the number of people able to work can affect a country's economy.

2. Measures of Obesity

Page 191 — Application Question

Q1 a) Robyn's BMI = $77.0 \div (1.78^2) = 24.302...$
$= \mathbf{24.3\ kg\ m^{-2}}$ (3 s.f.)
Asuka's BMI = $75.0 \div (1.55^2) = 31.217...$
$= \mathbf{31.2\ kg\ m^{-2}}$ (3 s.f.)
Remember, the BMI formula uses height in m. To convert cm to m, you divide by 100, so 178 cm = 1.78 m.
b) Robyn is in the healthy weight category.
Asuka is in the obese category.
Asuka may be recommended to lose weight by a doctor.

3. Treating Cardiovascular Disease

Page 195 — Fact Recall Questions

Q1 Disease of the heart or blood vessels.
Q2 A reduction in blood pressure helps to prevent damage to blood vessels. This reduces the risk of fatty deposits forming, which restrict blood flow.
Q3 E.g. it could cause a heart attack / bleeding / clotting / infection / stroke.

Page 195 — Application Questions

Q1 Smoking is a lifestyle factor which increases the risk of cardiovascular disease. By stopping smoking, Clifford will reduce the risk of further development of the disease and help to prevent a heart attack or stroke.
Q2 The time the surgery takes is shorter for having a stent compared to having coronary bypass surgery. The patient is also likely to spend less time in hospital and recover faster if they have a stent inserted (compared to having coronary bypass surgery). Although there is a higher chance of needing repeat surgery with a stent, the benefits may outweigh this risk.

Page 197 — Non-Communicable Diseases Exam-style Questions

1 a) E.g. waist circumference = 0.72 m = 72 cm
waist-to-hip ratio =
waist circumference ÷ hip circumference
$= 72 \div 89 = 0.8089... =$ **0.81 (2 s.f.)**
OR
hip circumference = 89 cm = 0.89 m
$0.72 \div 0.89 = 0.8089... =$ **0.81 (2 s.f.)**
(2 marks for the correct answer to 2 significant figures or 1 mark for converting measurements to the same units.)
b) Nadira is more at risk because she has a higher waist-to-hip ratio than Moira so she carries more weight around her middle ***(1 mark)***. This means she is at higher risk of developing obesity-related diseases such as type 2 diabetes ***(1 mark)***.
c) E.g. liver disease / liver cancer ***(1 mark)***. Drinking too much alcohol causes damage to liver cells which leads to disease ***(1 mark)***.

2 a) $(3 \div 154) \times 100 = 1.948... =$ **1.9%** ***(1 mark)***
b) By keeping the artery open, stents can help to increase blood flow ***(1 mark)***. People who have had a heart attack are likely to have narrowed coronary arteries, so putting stents in these arteries can prevent another heart attack ***(1 mark)***.
c) E.g. yes, because the results show that patients are less likely to die after having a drug-eluting stent inserted compared to a bare-metal stent ***(1 mark)***. Also renarrowing of the artery is much less likely in patients treated with a drug-eluting stent (9%) compared to those treated with a bare-metal stent (21%) ***(1 mark)***. The trial was fairly large (307 patients) which means the results are likely to be representative of the whole population ***(1 mark)***.

Topic 6 — Plant Structures and Their Functions

1. Photosynthesis

Page 199 — Fact Recall Questions

Q1 glucose
Q2 carbon dioxide
Q3 oxygen
Q4 a) chloroplasts
b) It absorbs light.
Q5 endothermic
Q6 carbon dioxide + water → glucose + oxygen
Q7 glucose

Page 199 — Application Question

Q1 Plant C. It received the most hours of sunlight, so it will have photosynthesised for longer. As photosynthesis produces glucose, it will have produced the most glucose.

2. Limiting Factors in Photosynthesis

Page 202 — Fact Recall Question

Q1 a) A factor which stops photosynthesis from happening any faster.

b) E.g. carbon dioxide concentration and temperature.

c) Increasing the light intensity increases the rate of photosynthesis (up to a point).

Page 203 — Application Questions

Q1

Environmental conditions	Most likely limiting factor
Outside on a cold winter's day.	temperature
In an unlit garden at 1:30 am, in the UK, in summer.	light
On a windowsill on a warm, bright day.	carbon dioxide concentration

Q2 a) Before point X, increasing the light intensity increases the rate of photosynthesis.

b) Flask A levels off at a lower point than Flask B because at this point, carbon dioxide concentration becomes the factor limiting the rate of photosynthesis in Flask A. Flask A has a lower carbon dioxide concentration than Flask B. All the other variables that affect the rate of photosynthesis are the same for both flasks.

3. Investigating the Rate of Photosynthesis

Page 205 — Application Question

Q1 $0.5\ \text{cm}^3 \div 3\ \text{min} = 0.166... =$ **$0.2\ \text{cm}^3\ \text{min}^{-1}$ (to 1 s.f.)**

4. The Inverse Square Law

Page 206 — Application Question

Q1 a) light intensity $= 1 \div d^2$,
$1 \div 15^2 = 0.004444... =$ **0.0044 a.u.**

b) light intensity $= 1 \div d^2$,
$1 \div 30^2 = 0.001111... =$ **0.0011 a.u.**

5. Transport in Plants

Page 209 — Fact Recall Questions

Q1 food substances / dissolved sugars/sucrose

Q2 Phloem tubes are made up of columns of elongated living cells. There are small pores (holes) in the end walls of the cells.

Q3 water and mineral ions

Q4 Water escapes from the leaves by evaporation and diffusion through the stomata. This creates a slight shortage of water in the leaves, which causes more water to be drawn up the xylem and into the leaves. This in turn causes more water to be drawn up the xylem from the roots.

Remember, the transpiration stream only goes on in the xylem — it doesn't involve the phloem.

Q5 Root hair cells have projections ("hairs") that give the roots a large surface area for absorbing water and mineral ions from the soil.

6. Transpiration and Stomata

Page 212 — Fact Recall Questions

Q1 The transpiration rate increases.

Q2 The uptake of water by a plant.

Q3 a) guard cells

b) When the plant is short of water, the guard cells lose water and become flaccid, making the stomata close.

Page 212 — Application Question

Q1 a) i) $26\ \text{mm} \div 30\ \text{min} = 0.866... =$ **$0.87\ \text{mm min}^{-1}$**

ii) $31\ \text{mm} \div 30\ \text{min} = 1.03... =$ **$1.0\ \text{mm min}^{-1}$**

b) E.g. A higher temperature means that more water is lost from the surface of the leaves by transpiration / the rate of transpiration is higher. This causes the plant to take up more water, so the bubble moves more.

7. Adaptations of Leaves and Plants

Page 214 — Fact Recall Questions

Q1 It helps to prevent water loss by evaporation.

Q2 So that light can pass through to the palisade layer, which contains lots of chloroplasts for photosynthesis.

Q3 E.g. the cells in the palisade mesophyll tissue contain lots of chloroplasts. The palisade mesophyll tissue is situated near the top of leaf, where it can get plenty of light.

Q4 They increase the rate of diffusion of gases through the leaf.

Q5 Having spines instead of leaves reduces the surface area for water loss by evaporation. They also reduce air flow near the surface of the plant, reducing diffusion of water vapour from the leaf to the air. Spines also help to stop animals eating the plant to get water.

8. Plant Hormones

Page 217 — Fact Recall Questions

Q1 The growth response of a plant to gravity.

Q2 More auxin accumulates on the side of the shoot that is in the shade than on the side in the light. Auxin promotes cell elongation in shoots, so the cells on the shaded side of the shoot elongate faster. This makes the shoot bend towards the light source.

Q3 More auxin accumulates on the lower side of the root. Auxin inhibits cell elongation in roots, so the cells on the top side of the root elongate faster. This makes the root bend downwards towards gravity.

9. Commercial Uses of Plant Hormones

Page 219 — Fact Recall Questions

Q1 auxins

Q2 gibberellins

Q3 Ethene stimulates fruit to ripen.

Page 219 — Application Question

Q1 a) For this type of plant, rooting powder B is the best type of rooting powder to use for the first three weeks of growth. This is because it's more effective at increasing root length each week for the first three weeks after planting, than rooting powder A.

It's important to remember that the results only apply to this particular type of plant. You also can't say what will happen after the three week period Dan recorded his results for.

b) It was a control. / To show that the results were likely to be due to the presence of the rooting powder and nothing else.

Pages 222-223 — Plant Structures and Their Functions Exam-style Questions

1 a) chloroplasts ***(1 mark)***

b) carbon dioxide + water → glucose + oxygen ***(1 mark)***

c) Light intensity B. At this light intensity, it took the shortest time for all of the discs to float ***(1 mark)***. This suggests that photosynthesis was happening the fastest at light intensity B ***(1 mark)***. The rate of photosynthesis increases with increasing light intensity ***(1 mark)***.

d) No. Increasing the light intensity will increase the rate of photosynthesis up to a certain point ***(1 mark)***. However, past this point increasing the light intensity will not increase the rate of photosynthesis ***(1 mark)*** as another factor (such as carbon dioxide concentration or temperature) will start to limit the rate ***(1 mark)***.

e) You would expect it to take more than 11 minutes, because the carbon dioxide concentration will be lower ***(1 mark)*** so the rate of photosynthesis will be slower/will be limited to a lower level than in the first experiment ***(1 mark)***.

With so little carbon dioxide present in the second experiment, you would expect carbon dioxide concentration to be the limiting factor rather than light intensity.

2 a) epidermis/epidermal tissue ***(1 mark)***

b) Palisade mesophyll tissue ***(1 mark)***, because most of the photosynthesis that takes place in a leaf happens in the palisade mesophyll tissue ***(1 mark)***.

3 a) A plant loses water through its stomata ***(1 mark)***. Evaporation/water loss is quickest in hot, dry conditions ***(1 mark)***. So closing the stomata when it is hot and dry and only opening them when it is cooler, will reduce water loss from the plant ***(1 mark)***.

b) Trapping water vapour close to the surface of the leaf will reduce the difference in the concentration of water molecules between the inside and outside of the leaf ***(1 mark)***. This will slow down water loss from the plant ***(1 mark)***.

Plants in dry conditions need to conserve as much water as possible because there's so little available in the environment.

4 a) E.g. the farmer could apply gibberellins to the unpollinated flowers of the tomato plants ***(1 mark)***.

b) Most weeds are broad-leaved, but wheat is narrow-leaved ***(1 mark)***. Selective weedkillers made from auxins will kill only the broad-leaved plants ***(1 mark)***.

c) ethene ***(1 mark)***

Topic 7 — Animal Coordination, Control and Homeostasis

Topic 7a — Hormones and Fertility

1. Hormones

Page 226 — Fact Recall Questions

Q1 By the blood (plasma).

Q2 false

A particular hormone will only affect certain organs, called target organs.

Q3 endocrine glands

Q4 E.g. testosterone

Q5 nerves

2. Adrenaline and Thyroxine

Page 228 — Fact Recall Questions

Q1 the adrenal glands

Q2 E.g. it helps to regulate (basal) metabolic rate.

Page 228 — Application Question

Q1 a) adrenaline

b) It increases blood flow to the muscles, so the cells receive more oxygen and glucose for increased respiration. This gives the muscles the extra energy they need for increased contraction. This will allow Pierre to 'fight' or to run away if necessary.

3. The Menstrual Cycle

Page 231 — Fact Recall Questions

Q1 The lining of the uterus breaks down and is released from the body.

Q2 Oestrogen and progesterone.

Q3 It causes the follicles to mature.

Q4 It stimulates the release of an egg/ovulation at around the middle (day 14) of the menstrual cycle. / It stimulates the remains of the ruptured follicle to develop into a corpus luteum.

Q5 progesterone

Q6 The pituitary gland and the ovaries.

Page 232 — Application Question

Q1 a) LH (luteinising hormone). LH is the hormone responsible for stimulating the release of an egg. The concentration of the hormone on the graph increases just before the middle of the cycle (day 14) — the time at which an egg is normally released.

b) the pituitary gland

c) LH is needed to stimulate the release of an egg. This woman's LH level peaks at a much lower level than the other woman's, suggesting that she may not be releasing an egg during her menstrual cycle. This could be the reason why she's struggling to have children.

4. Controlling Fertility

Page 234 — Fact Recall Questions

Q1 To stimulate the production of multiple eggs (so that more than one egg can be collected).

Q2 It inhibits FSH production, and so prevents egg maturation and therefore release.

Q3 Barrier methods are designed to put a barrier between the sperm and egg so they don't meet.

Page 236 — Hormones and Fertility Exam-style Questions

1 a) i) E.g. hormonal contraceptives are more effective than barrier contraceptives. / If using hormonal contraceptives correctly, a couple doesn't need to think about contraceptives each time they have intercourse, unlike with barrier methods of contraception ***(1 mark)***.

ii) E.g. hormonal contraceptives don't protect against sexually transmitted infections (STIs) whereas some barrier methods/condoms do protect against STIs ***(1 mark)***.

b) E.g. progesterone stimulates the production of thick cervical mucus which prevents sperm getting through the cervix and reaching the egg. / Progesterone can inhibit egg maturation and therefore the release of an egg ***(1 mark)***.

c) i) E.g. clomifene therapy ***(1 mark)***

ii) The drug clomifene causes more FSH and LH to be released by the body ***(1 mark)***. This stimulates egg maturation and ovulation ***(1 mark)***. By knowing when the woman will be ovulating, a couple can have intercourse during this time to improve the chance of becoming pregnant ***(1 mark)***.

d) progesterone ***(1 mark)***

2 a) C ***(1 mark)***

b) When the level of thyroxine in the blood is lower than normal, the hypothalamus is stimulated to release thyrotropin releasing hormone/TRH ***(1 mark)***. TRH stimulates the secretion of thyroid stimulating hormone/TSH from the pituitary gland ***(1 mark)***. TSH stimulates the thyroid gland to release thyroxine, so the level of thyroxine in the blood rises back to normal ***(1 mark)***.

c) 1 day = 24 hours
1860 ÷ 24 = 77.5
77.5 × 6 = **465 kcal**
(2 marks for correct answer, otherwise 1 mark for correct working.)

Topic 7b — Homeostasis

1. Homeostasis

Page 237 — Fact Recall Questions

Q1 Homeostasis is the regulation of the conditions inside your body (and cells) to maintain a constant internal environment, in response to changes in both internal and external conditions.

Q2 Any two from: e.g. temperature / blood glucose content / water content of the body.

2. Controlling Blood Glucose

Page 242 — Fact Recall Questions

Q1 the pancreas

Q2 Insulin makes body cells take up more glucose from the blood.

Q3 the pancreas

Q4 It causes glycogen to be converted into glucose which then enters the blood.

Q5 A condition where the pancreas produces very little or no insulin, which means blood glucose can rise to a dangerous level.

Q6 Any two from: e.g. eating a healthy diet / exercising regularly / losing weight if necessary / medication/insulin injections if necessary.

Page 242 — Application Question

Q1 a) Glucagon, because the subject's blood glucose level rises following the injection. Glucagon causes glycogen to be converted back into glucose, which enters the blood, causing the blood glucose level to rise.

b) i) insulin

ii) The blood glucose level would fall following the injection, as insulin causes body cells to take up more glucose from the blood, causing the blood glucose level to fall.

3. Thermoregulation

Page 245 — Fact Recall Questions

Q1 Receptors in the thermoregulatory centre that are sensitive to the temperature of the blood flowing through the brain. Receptors in the skin/dermis and epidermis that are sensitive to skin temperature.

Q2 a) They dilate.

b) More blood flows close to the surface of the skin, which makes it easier for energy to be transferred from the skin to the environment.

Q3 Temperature receptors detect that the core body temperature is too low. The receptors send impulses to the hypothalamus, which processes the information and sends impulses to the effectors. The effectors produce a response that reduces the amount of heat lost from the body (so the body warms up).

Page 245 — Application Question

Q1 a) Any two from: e.g. erector muscles in the dermis will contract, making hairs on the skin stand up. / The amount of sweat her sweat glands produce will decrease. / The blood vessels supplying her skin capillaries will constrict/get narrower. / She will shiver/her muscles will contract automatically.

b) E.g. the hairs on her skin standing up trap an insulating layer of air next to her skin, reducing the amount of energy transferred to the environment. / The lack of sweat reduces the cooling that occurs from sweat evaporating from her skin. / The constriction of blood vessels supplying the skin capillaries reduces the amount of blood that flows close to the surface of the skin, meaning that less energy is transferred from the skin to the environment. / Her shivering/the automatic contraction of her muscles helps to raise body temperature as it increases the rate of respiration, which transfers some energy to warm the body.

4. Osmoregulation and The Kidneys

Page 249 — Fact Recall Questions

Q1 The regulation of water content in the body.
It's important to keep cells functioning normally / stop cells from bursting/shrinking due to changes in the osmotic conditions.

Q2 Urea is produced in the liver from the breakdown of excess amino acids.

Q3 selective reabsorption

Q4 Any two from: e.g. glucose / water / ions

Q5 The liquid part of the blood is forced out of the glomerulus and into the Bowman's capsule at high pressure. Large molecules and cells can't pass through the membranes between the glomerulus and the Bowman's capsule, so they stay in the blood.

Q6 If the water content of the blood gets too low, a receptor in the brain detects this. The brain then instructs the pituitary gland to release ADH into the blood. ADH makes the collecting ducts of the nephrons more permeable to water, so that more water is reabsorbed into the blood. This increases the water content of the blood so it gets back to normal.

Page 249 — Application Questions

Q1 The cell will burst, as water will move into the cell by osmosis.

Q2 a) i) (volume of water reabsorbed ÷ volume of water filtered) × 100
= (178.2 ÷ 180) × 100 = **99%**

ii) It would increase. The person would lose more water in sweat, so the kidneys would reabsorb more water in order to balance this loss.

Remember, we sweat more when it's hot to cool ourselves down. We also sweat more during exercise, as this also raises the body temperature.

iii) A small amount of concentrated urine would be produced.

b) 720 – 500 = **220 millimoles per day**

If a greater amount of a substance is filtered by the kidneys than is reabsorbed, then the remainder will end up in the urine.

5. Kidney Failure

Page 251 — Fact Recall Questions

Q1 false

People with kidney failure need to have dialysis regularly to keep the concentrations of dissolved substances in the blood at normal levels.

Q2 The damaged kidney is replaced with a healthy kidney from a donor.

Page 252 — Application Question

Q1 a) So that useful sodium ions won't be lost from the blood during dialysis, as they won't diffuse across the barrier into the dialysis fluid.

b) i) Urea is a waste product which is carried to the kidneys in the blood.

ii) As there is some urea in the plasma there needs to be less in the dialysis fluid for urea to be removed from the blood. If there is no urea in the dialysis fluid at the start of the dialysis session, then there will be a concentration gradient between the blood and the dialysis fluid, allowing urea to leave the blood via diffusion.

c) E.g. there would be a similar amount. Glucose isn't a waste product — it's a substance that the body needs. If there are similar amounts in both the blood and the dialysis fluid then glucose won't be lost from the blood during dialysis.

Page 254 — Homeostasis
Exam-style Questions

1 a) B ***(1 mark)***

b) insulin ***(1 mark)***

c) People with type 1 diabetes produce little or no insulin ***(1 mark)***. Injecting insulin stops their blood glucose level from rising to a dangerous level ***(1 mark)*** as insulin causes the body's cells to take up glucose from the blood ***(1 mark)***.

2 a) A ***(1 mark)***

b) The liquid part of the blood is ultrafiltered through the membranes of the glomerulus at the start of the nephron into the Bowman's capsule / forced out of the glomerulus into the Bowman's capsule at high pressure ***(1 mark)***. The filtered liquid then flows along the nephron and useful substances are selectively reabsorbed ***(1 mark)***. Whatever isn't reabsorbed leaves the nephron via the collecting duct and passes to the bladder as urine ***(1 mark)***.

c) There is a higher concentration of sodium ions in the urine than in the blood ***(1 mark)***. This is because excess sodium ions have been filtered out of the blood in the kidneys and become part of the urine ***(1 mark)***.

Topic 8 — Exchange and Transport in Animals

1. Exchange of Materials

Page 257 — Application Question

Q1 a) Cell A:

$SA = 2 \times (0.2 \times 0.4) + 2 \times (1 \times 0.4) + 2 \times (1 \times 0.2)$
$= 0.16 + 0.8 + 0.4 = 1.36\ \mu m^2$
$V = 1 \times 0.4 \times 0.2 = 0.08\ \mu m^3$
$SA : V = 1.36 : 0.08$
$1.36 \div 0.08 = 17,\ 0.08 \div 0.08 = 1$
so ratio is **17 : 1**

Cell B:

$SA = 2 \times (0.5 \times 0.5) + 4 \times (2 \times 0.5) = 0.5 + 4$
$= 4.5\ \mu m^2$
$V = 2 \times 0.5 \times 0.5 = 0.5\ \mu m^3$
$SA : V = 4.5 : 0.5$
$4.5 \div 0.5 = 9,\ 0.5 \div 0.5 = 1$
so ratio is **9 : 1**

b) Cell A, because it has the largest surface area to volume ratio.

2. Factors Affecting the Rate of Diffusion

Page 259 — Fact Recall Questions

Q1 A large surface area to diffuse across.
A large concentration gradient / a big difference in concentration between the area that a substance is diffusing from and the area that a substance is diffusing to.
A thin exchange surface / a short diffusion pathway.

Q2 The rate of diffusion will double.

Page 259 — Application Question

Q1 rate of diffusion =
(surface area × concentration difference) ÷ thickness of membrane
rate of diffusion = $(80 \times 0.5) \div 2$
$= \mathbf{20\ a.u.}$

3. The Alveoli

Page 261 — Fact Recall Questions

Q1 alveoli

Q2 B. The concentration of oxygen is higher in the air in the alveoli than in the blood in the capillaries. Diffusion takes place from an area of higher concentration to an area of lower concentration.

Q3 Any three from: a large surface area / a moist lining for dissolving gases / very thin walls / a good blood supply to maintain the concentration gradients of oxygen and carbon dioxide.

Page 261 — Application Question

Q1 The destruction of the alveolar walls will reduce the surface area of the alveoli in the lungs. This will result in a decrease in gas exchange.

4. Circulatory System — The Blood

Page 263 — Fact Recall Questions

Q1 a) haemoglobin
b) It carries oxygen.

Q2 To defend against microorganisms that cause disease.

Q3 To help blood to clot at a wound to prevent excessive blood loss and entrance of microorganisms.

Q4 plasma

5. Circulatory System — The Blood Vessels

Page 265 — Fact Recall Question

Q1 capillaries

Page 265 — Application Question

Q1 A. Arteries carry blood at a higher pressure than veins and their walls are more muscular as a result. Blood vessel A carries blood at a higher pressure than blood vessel B, and so is more likely to be an artery and have more muscle in its walls.

6. Circulatory System — The Heart

Page 269 — Fact Recall Questions

Q1 One circuit pumps deoxygenated blood from the heart to the lungs, and then oxygenated blood from the lungs back to the heart. The other circuit pumps oxygenated blood from the heart to the rest of the body, and then deoxygenated blood from the rest of the body back to the heart.

Q2 right atrium, right ventricle, left atrium, left ventricle

Q3 a) vena cava and pulmonary vein
b) pulmonary artery and aorta

Page 269 — Application Questions

Q1 vena cava

Q2 $6.46\ dm^3\ min^{-1} = 6460\ cm^3\ min^{-1}$
stroke volume = cardiac output ÷ heart rate
$= 6460\ cm^3\ min^{-1} \div 85$ bpm
$= \mathbf{76\ cm^3}$

To convert dm^3 into cm^3, you multiply by 1000.

7. Respiration

Page 272 — Fact Recall Questions

Q1 E.g. mammals use energy for building larger molecules from smaller ones, to contract muscles and to keep warm.

Q2 Respiration using oxygen. / The process of transferring energy from glucose using oxygen.

Q3 It transfers energy to the environment.

Q4 The body uses anaerobic respiration when it can't get enough oxygen to the muscles for aerobic respiration, e.g. during vigorous exercise.

Q5 glucose → lactic acid

Page 272 — Application Questions

Q1 a) oxygen
  b) water

Q2 The limited availability of oxygen in the soil means that the root cells of rice plants will have to respire anaerobically. Anaerobic respiration in plants produces ethanol, so the concentration of ethanol will build up in the plant root cells. The root cells will need a high tolerance for ethanol so that they are not killed by it.

8. Investigating Respiration

Page 275 — Application Question

Q1 a) The cotton wool ensures that the maggots don't come into contact with the harmful soda lime granules.
  b) To absorb the carbon dioxide produced by the maggots during respiration and stop it from affecting the results of the experiment.
  c) A. The maggots will be taking in oxygen during respiration, which decreases the volume of air in their test tube. This reduces the pressure in their test tube, which causes the coloured fluid to move towards it.
  d) The further the liquid moves, the more oxygen has been taken up by the maggots, and so the higher the rate of respiration. Since the liquid moved further at 20 °C, it suggests that an increase in temperature increases the rate of respiration.

Pages 278-279 — Exchange and Transport in Animals Exam-style Questions

1 a) A — vena cava ***(1 mark)***, B — right ventricle ***(1 mark)***, C — left atrium ***(1 mark)***.
  b) Structure D/the left ventricle has a thicker wall because it needs to pump blood around the whole body at a high pressure ***(1 mark)***, whereas structure B/the right ventricle only has to pump blood to the lungs ***(1 mark)***.
  c) X, because veins have thinner walls than arteries ***(1 mark)***.

2 a) Patient A, because the number of white blood cells in their blood is below the normal range / lower than the number of white blood cells in Patient B's blood ***(1 mark)***. White blood cells help to defend the body against microorganisms that cause disease, so with fewer white blood cells in their blood, Patient A is more likely to get an infection ***(1 mark)***.
  b) Red blood cells ***(1 mark)***. They have a biconcave shape to give them a large surface area for absorbing oxygen ***(1 mark)***. They contain a red pigment called haemoglobin, which carries the oxygen ***(1 mark)***. They don't have a nucleus, allowing for more room for haemoglobin, meaning that they can carry more oxygen ***(1 mark)***.

3 a) surface area:
  $0.6 \times 0.6 = 0.36$
  $3.0 \times 0.6 = 1.8$
  $(2 \times 0.36) + (4 \times 1.8) = 7.92\ \mu m^2$
  volume:
  $0.6 \times 0.6 \times 3.0 = 1.08\ \mu m^3$
  ratio:
  $7.92 \div 1.08 = 7.3333... = 7$
  so the ratio is **7 : 1** ***(3 marks for correct answer, otherwise 1 mark for correct surface area and 1 mark for correct volume.)***
  b) Because it is a single-celled organism ***(1 mark)***, so it has a large surface area to volume ratio ***(1 mark)***. This means it can exchange enough substances across its cell membrane/outer surface to meet its needs ***(1 mark)***.

4 a) glucose + oxygen → carbon dioxide + water ***(1 mark for glucose and oxygen on the left-hand side of the equation, 1 mark for carbon dioxide and water on the right.)***
  b) Anaerobic respiration forms less ATP than aerobic respiration, which shows that it transfers less energy ***(1 mark)***. This is because glucose is not completely broken down in anaerobic respiration ***(1 mark)***.

Topic 9 — Ecosystems and Material Cycles

Topic 9a — Ecosystems and Biodiversity

1. Ecosystems and Interactions Between Organisms

Page 282 — Fact Recall Questions

Q1 A population is a group containing only one species, whereas a community is a group containing different species.

Q2 an individual organism

Page 282 — Application Questions

Q1 D

Q2 A mutualistic relationship because both organisms benefit from it. The crabs are camouflaged by the algae, so they are less likely to be spotted by predators and eaten, and the algae get a place to live.

2. Abiotic and Biotic Factors

Page 284 — Fact Recall Questions

Q1 Any three from, e.g. temperature, light intensity, water availability, pollution.

Q2 E.g. competition, predation.

Page 284 — Application Question

Q1 a) i) It decreased.
    ii) an abiotic factor

Remember, it's the oxygen concentration that changed, and oxygen isn't alive — making it an abiotic factor.

  b) The population size of the herons is likely to have decreased because there were fewer fish to eat.

Here the environmental change was caused by a biotic factor — the availability of food.

3. Investigating Ecosystems

Page 288 — Fact Recall Questions

Q1 E.g. you would place the quadrat on the ground at a random position in the first sample area and count the number of the organisms within the quadrat. You would then repeat this many times. Next you would repeat this whole process in the second sample area. Finally you would work out the mean number of organisms per quadrat or the population size in each sample area and compare the results.

Q2 You would mark out a line across the area you want to study using a tape measure. You would then place quadrats next to each other/at regular intervals along the line. Next you would collect data by counting all of the organisms of the species you're interested in each quadrat/estimating the percentage cover. Finally, you would repeat the process and find the mean number of organisms (or mean percentage cover) for each quadrat.

Page 288 — Application Questions

Q1 a) $1 + 5 + 5 + 20 + 43 + 37 = 111$
$111 \div 6 =$ **18.5**

Remember the mean is the average you get by adding together all the values in the data and dividing it by the number of values that you have.

b) End B, as the amount of bulrushes is lower here and you would expect there to be fewer bulrushes further away from the pond as they prefer moist soil or shallow water.

Q2 First calculate how many of the quadrats used by the conservationists would fit in 1 m^2: $1 \div 0.25 = 4$
Then work out how many slugs there would be in 1 m^2: $4 \times 2.5 = 10$
Finally, work out how many slugs there would be in 2000 m^2: $10 \times 2000 =$ **20 000 slugs in the area**

4. Ecosystems and Energy Transfers

Page 291 — Fact Recall Questions

Q1 By organisms eating other organisms.

Q2 Any two from: e.g. through respiration/movement/as heat / not all of an organism gets eaten / not all of an organism can be digested.

Q3 Energy is lost at each trophic level, so after 4 or 5 trophic levels there's not enough energy left to support more organisms.

Page 291 — Application Question

Q1 a) phytoplankton
b) bass
c) Because biomass has been lost between the krill trophic level and the herring trophic level in the food chain.

5. Calculating Energy Transfers

Page 292 — Application Question

Q1 $\frac{0.055 \text{ kg}}{0.56 \text{ kg}} \times 100$
$=$ **9.8%**

6. Human Impacts on Biodiversity

Page 295 — Application Questions

Q1 a) Reforestation could increase biodiversity in Scotland, by increasing the number and variety of tree species. This, in turn, could increase the number and variety of animal species by providing them with food and shelter.
b) E.g. it could increase ecotourism, bringing money into the country. It could provide new jobs through reforestation schemes/tourism.

Q2 E.g. the lower biodiversity could be because excess fertilisers are running off the fields into the water, causing eutrophication. Eutrophication is an excess of nutrients in the water, which causes increased algal growth followed by the death of other organisms in the water (such as plants and fish) due to lack of oxygen.

7. Food Security

Page 297 — Fact Recall Questions

Q1 As there are more people to feed, it means that more food needs to be produced so that each person has enough to eat.

Q2 Increasing meat consumption means that more animals need to farmed. For a given area of land, you can produce a lot more food for humans by growing crops rather than by grazing animals, so it's harder to produce enough food through animal farming.

Q3 E.g. growing biofuels as a renewable energy source takes up land that could be used for food crops. We need to balance the need for biofuels with the need to grow more food now and in the future. / High input costs of farming (e.g. the price of fertilisers, fuel and machinery) may make it too expensive for farmers to continue farming and maintain food production in the future.

Pages 299-300 — Ecosystems and Biodiversity Exam-style Questions

1 a) $55 + 41 + 57 = 153$
$153 \div 3 =$ **51**
(2 marks for correct answer, otherwise 1 mark for correct working.)

b) The number of limpets increases as you move away from the water's edge, and then begins to decrease after the position of quadrat 3 ***(1 mark)***. The low number of limpets in quadrats closest to the water's edge could be due to competition for space from other organisms ***(1 mark)***. The decrease in the number of limpets after quadrat 3 could be due to there being less water available further from the water's edge, which increases the limpets' chance of drying out ***(1 mark)***.

c) To make sure their samples were representative of the whole shore line ***(1 mark)*** and therefore to increase the validity of their results ***(1 mark)***.

2 a) C, because algae are at the start of the food chain/ are producers ***(1 mark)***.
b) Width of bar B = 6 squares.
Width of bar C = 60 squares.
So ratio of bar C to bar B = 60:6 = **10:1**
(2 marks for correct answer, otherwise 1 mark for correctly finding the widths of bar B and bar C).
c) Energy is lost when organisms don't eat every single part of the organism they're consuming because some parts are inedible ***(1 mark)***. It is also lost when some parts that do get eaten can't be digested ***(1 mark)***. Some energy is transferred out of the food chain as heat during respiration/as the organisms move ***(1 mark)***.
d) It provides the energy ***(1 mark)*** needed for producers/green plants and algae to photosynthesise ***(1 mark)*** and produce biomass ***(1 mark)***, which is passed on throughout the food chain by organisms eating each other ***(1 mark)***.

3 a) It is decreasing ***(1 mark)***.
b) The outbreak of rabies is responsible for the trend ***(1 mark)***. In the years when there were rabies outbreaks the population size fell ***(1 mark)***. For example, the numbers fell from 401 to 327 in 2008 / 341 to 265 in 2011 when there was a rabies outbreak ***(1 mark)***.

There's a lot of data to look at in the table so think carefully about what you're looking for. The numbers of prey don't really change much throughout the study so that's unlikely to have caused the change in the number of wolves, so it's sensible to look at the outbreaks of rabies.

c) It has made the wolf population move to higher ground ***(1 mark)*** from an average height of 3.4 km above sea level in 2007 to an average height of 4 km above sea level in 2012 ***(1 mark)***.

Topic 9b — Material Cycles

1. The Carbon Cycle

Page 302 — Fact Recall Questions

Q1 CO_2 is removed from the atmosphere by green plants and algae during photosynthesis, and the carbon is used to make glucose. The glucose can be turned into carbohydrates, fats and proteins that make up the bodies of the plants and algae.
Q2 By animals eating plants or other animals.
Q3 E.g. dead leaves are fed on by decomposers. These organisms release CO_2 when they respire.

Page 302 — Application Question

Q1 The carbon in the marine organisms' shells is in a biotic part of the marine ecosystem. When these shells eventually form limestone rocks, it becomes an abiotic component of the ecosystem. The carbon moves to another abiotic component of the ecosystem when it is released into the air.

2. The Water Cycle

Page 305 — Fact Recall Questions

Q1 It cools and condenses.
Q2 E.g. rain, snow, hail
Q3 Water that is suitable for drinking.
Q4 Not having enough precipitation / a shortage of fresh water.

Page 305 — Application Questions

Q1 Yes. Water evaporates from plants in transpiration and cools and condenses to form clouds as it gets higher up. Water falls from the clouds as precipitation onto land. Some of this water then drains into the sea.
Q2 a) E.g. because they have very little rainfall/droughts during the summer months, which will limit the amount of potable water available. There will be added pressure on potable water supplies due to the large numbers of tourists visiting the islands. Desalination plants will remove the salt from sea water (which the islands have easy access to) making it suitable for drinking. This will help the islands to produce enough potable water for everyone.
b) E.g. the solar panels will capture energy from the Sun and use it to heat the sea water. This is part of the thermal distillation process — heat causes the water to evaporate, leaving the salt behind. The pure water can then be condensed and collected for drinking.

3. The Nitrogen Cycle

Page 307 — Fact Recall Questions

Q1 a) Nitrifying bacteria turn ammonia in decaying matter into nitrites or nitrites into nitrates, which can be taken up by plants from the soil.
b) Decomposers break down dead organisms and waste matter to produce ammonia, which nitrifying bacteria then act upon.
Q2 denitrifying bacteria

Page 307 — Application Question

Q1 E.g. she could grow a different crop in each vegetable bed each year, in a cycle that includes a nitrogen-fixing crop (e.g. peas or beans) in one of the years. The nitrogen-fixing crop will help to put nitrates back into the soil for the next crop to use the following year. This will help the crops to grow better and should help to increase the yield of vegetables.

4. Indicator Species

Page 309 — Application Questions

Q1 No because there could be other reasons for the absence of freshwater shrimp in the stream, besides the stream being polluted, e.g. competition from other organisms / a lack of food.
Q2 5.6 km, because at this distance there is the lowest percentage cover of lichen. Lichen are sensitive to the amount of sulfur dioxide in the atmosphere, so there will be fewer of them around sources of sulfur dioxide, such as power stations.

5. Decomposition

Page 312 — Application Questions

Q1 a) Dried pasta has less water in it than fresh pasta. Without water the microorganisms that decompose food can't survive, so dried pasta keeps for longer than fresh pasta.

b) Salt causes the microorganisms that decompose food to lose water by osmosis, so they die. This means salted fish will have fewer decomposers and keep longer than fresh fish.

Q2 a) To let oxygen in — many microorganisms which break down waste material need oxygen for respiration.

b) The presence of water vapour would increase the moisture inside the compost bin and, as microorganisms need water to carry out biological processes, it would help compost to be made more quickly.

Pages 314-315 — Material Cycles

Exam-Style Questions

1 a) B ***(1 mark)***

It's easy to get the different types of bacteria in the nitrogen cycle mixed up — make sure you learn what each type does.

b) It is a mutualistic relationship (from which both organisms benefit) ***(1 mark)***. The bacteria provide the plants with nitrates and obtain sugars in return ***(1 mark)***.

2 How to grade your answer:

Level 0: There is no relevant information. ***(No marks)***

Level 1: There is a brief description of one or two steps in the carbon cycle. The points made are basic and not linked together. ***(1 to 2 marks)***

Level 2: There is a description of three or four steps in the carbon cycle. Some of the points made are linked together. ***(3 to 4 marks)***

Level 3: There is a detailed description of five or six steps in the carbon cycle with named processes. The points made are well-linked and the answer has a clear and logical structure. ***(5 to 6 marks)***

Here are some points your answer may include:

The grass absorbs carbon dioxide from the air in photosynthesis.
The grass uses this carbon to make glucose/carbohydrates/fats/proteins.
This carbon is passed onto the cows when the cows eat the grass, and onto humans when the humans eat the cows, so it moves through the food chain.
Dead organisms/waste materials are broken down/decayed by decomposers/microorganisms.
All the organisms/the grass/cows/humans/microorganisms respire and release carbon dioxide into the atmosphere.
Some decayed organisms go on to eventually form fossil fuels.
Combustion/burning of fossil fuels also releases carbon dioxide into the air.

3 a) The removal of salts/mineral ions from salt water ***(1 mark)***.

b) i) In reverse osmosis, the water molecules are forced to move from an area of lower water concentration / higher salt concentration to an area of higher water concentration / lower salt concentration ***(1 mark)*** across a partially permeable membrane. The membrane prevents the movement of the dissolved salts, so pure water is produced ***(1 mark)***.

ii) Energy from the Sun makes water evaporate from the sea, turning it into water vapour ***(1 mark)***. The water vapour is carried upwards, until it cools and condenses to form clouds ***(1 mark)***. Fresh water then falls to Earth as precipitation/rain ***(1 mark)***.

4 a) i) E.g. to allow a fair comparison between the loss of mass of the two bins / because each bin may have had slightly different starting masses ***(1 mark)***.

ii) 8 weeks = 8 × 7 = 56 days.
After 8 weeks, Bin 1 had lost 10% of its mass.
$10 \div 56 = 0.178... = \mathbf{0.18\%\ day^{-1}}$
(2 marks for the correct answer, otherwise 1 mark for 56 days)

b) E.g. because the compost was broken down/decomposed by microorganisms ***(1 mark)***. These take in carbon from the compost ***(1 mark)*** and release it into the atmosphere as carbon dioxide when they respire (so the compost loses mass) ***(1 mark)***.

The compost may have also lost water as it decomposed (e.g. through evaporation). If you gave this alternative explanation in the exam, you could have still picked up marks.

c) Bin 1 because it lost a greater percentage of its mass in the 12 week period, indicating that it decayed faster ***(1 mark)***. Higher temperatures tend to speed up the rate of decay ***(1 mark)***, therefore it was likely to be in the area of full sunshine, which would have been warmer than the shady area ***(1 mark)***.

d) No. Blackspot fungus only grows where the concentration of sulfur dioxide in the atmosphere is low ***(1 mark)***, therefore the presence of the fungus indicates that the local air quality is good/clean ***(1 mark)***.

Glossary

A

Abiotic factor
A non-living factor of the environment.

Accurate result
A result that is very close to the true answer.

Acquired characteristic
A characteristic that an organism gets during its lifetime due to environmental effects.

Acrosome
A subcellular structure in the head of a sperm cell, which stores enzymes needed by the sperm to digest through the egg cell membrane.

Active site
The part of an enzyme where a substrate molecule binds.

Active transport
The movement of particles against a concentration gradient (i.e. from an area of lower concentration to an area of higher concentration) using energy transferred during respiration.

Adrenal gland
A gland that produces the hormone adrenaline.

Adrenaline
A hormone secreted by the adrenal glands that is released in response to stressful situations in order to prepare the body for 'fight or flight'.

Aerobic respiration
The reactions involved in breaking down glucose using oxygen, to transfer energy.

Allele
An alternative version of a gene.

Alveolus
A tiny air sac in the lungs, where gas exchange occurs.

Amylase
The enzyme amylase catalyses the breakdown of starch to maltose.

Anaerobic respiration
The incomplete breakdown of glucose, which takes place in the absence of oxygen.

Anomalous result
A result that doesn't seem to fit with the rest of the data.

Antibiotic
A drug used to kill or prevent the growth of bacteria inside of the body.

Antibiotic resistance
When bacteria aren't killed by an antibiotic.

Antibody
A protein produced by white blood cells in response to the presence of an antigen (e.g. on the surface of a pathogen).

Anticoagulant
A drug taken to reduce likelihood of blood clot formation.

Anticodon
A sequence of three nucleotide bases in tRNA that is complementary to a sequence of three bases in mRNA (an mRNA codon).

Anti-diuretic hormone (ADH)
A hormone that makes the collecting ducts in the kidney nephrons more permeable, so that the kidneys reabsorb more water.

Antigen
A molecule (often found on the surface of a cell) that triggers an immune response.

Antihypertensive
A drug taken to lower blood pressure.

Antiseptic
An agent used to kill or prevent the growth of bacteria on the outside of the body, e.g. the skin.

Aorta
A blood vessel (artery) which transports blood from the heart to the rest of the body (excluding the lungs).

Artery
A blood vessel that carries blood away from the heart.

Aseptic technique
A method designed to prevent contamination from harmful microorganisms.

Asexual reproduction
Where organisms reproduce by mitosis to produce genetically identical offspring.

Atrium
A chamber of the heart into which blood enters from either the pulmonary vein or the vena cava.

Auxin
A plant hormone that controls the growth of a plant in response to different stimuli.

Axon
An extension of a neurone, which carries nervous impulses away from the cell body.

B

Bacterium
A single-celled microorganism without a 'true' nucleus. Some bacteria are able to cause disease.

Base triplet
A sequence of three nucleotide bases that codes for an amino acid.

Belt transect
A transect along which quadrats are placed.

Bias
Prejudice towards or against something.

Biodiversity
The variety of different species of organisms on Earth or within an ecosystem.

Biological catalyst
A substance that increases the speed of a chemical reaction both inside and outside living cells.

Biological control
A method of pest control that uses living organisms to control pest numbers.

Biomass
The mass of living material.

Biotic factor
A living factor of the environment.

Blind trial
A clinical trial where the patients don't know whether they have received the drug or the placebo.

Blood
A tissue which transports substances around the body in the circulatory system.

B-lymphocyte
A type of white blood cell involved in the specific immune response that produces antibodies.

Bowman's capsule
A sac of tissue surrounding the glomerulus in a kidney nephron. The products of ultrafiltration collect here.

C

Cancer
A disease caused by a mass of abnormal cells, which divide uncontrollably and invade and destroy surrounding tissue.

Capillary
A type of blood vessel involved in the exchange of materials at tissues.

Carbohydrase
A type of enzyme that converts carbohydrates into simple sugars.

Carbohydrate
A large biological molecule made up of long chains of sugar molecules.

Cardiac output
The total volume of blood pumped by a ventricle every minute.

Cardiovascular disease
Disease of the heart or blood vessels.

Carrier
A person who carries the allele for an inherited disorder, but who doesn't have any symptoms of the disorder.

Catalyst
A substance which increases the speed of a reaction, without being changed or used up in the reaction.

Cataract
Clouding of the lens in the eye.

Categoric data
Data that comes in distinct categories (e.g. sex — male and female, etc.).

Causation
When a change in one variable causes a change in another.

Cell cycle
The process that all body cells from multicellular organisms use to grow and divide.

Cell differentiation
The process by which a cell becomes specialised for its job.

Cell elongation
The process by which a plant cell expands, so that the plant grows.

Cell membrane
A membrane surrounding a cell, which holds it all together and controls what goes in and out.

Cell wall
A structure surrounding some cell types, which gives strength and support.

Central Nervous System (CNS)
The brain and spinal cord. It's where reflexes and actions are coordinated.

Cerebellum
A structure at the back of the brain responsible for muscle coordination and balance.

Cerebral hemisphere
One half of the cerebrum. The cerebrum is made up of two cerebral hemispheres — the left and the right.

Cerebrum
The largest part of the brain responsible for things like movement, intelligence, memory, language and vision.

Chlorophyll
A green substance found in chloroplasts which absorbs light for photosynthesis.

Chloroplast
A structure found in plant cells and algae, which contains chlorophyll. Chloroplasts are the site of photosynthesis.

Chromosome
A long, coiled-up molecule of DNA, which carries genes.

Ciliated epithelial cell
A cell lining the surface of an organ that has cilia (tiny hair-like structures used to move substances along) covering its upper surface.

Circulatory system
A system which uses blood to transport materials around the body.

Clinical trial
A set of drug tests on human volunteers.

Clone
An organism that is genetically identical to another organism.

Codominance
When two alleles of a gene are expressed in the same phenotype.

Codon
A sequence of three nucleotide bases in mRNA that codes for an amino acid.

Collecting duct
A tube at the end of a kidney nephron where water can be reabsorbed into the blood and urine passes out of the kidney.

Colour blindness
The inability to tell the difference between certain colours.

Communicable disease
A disease that can spread between individuals.

Community
All the organisms of different species living in a habitat.

Competition (in ecosystems)
When organisms strive against other organisms to win resources such as food, water, mates, etc.

Complementary base pairing
Hydrogen bonding between specific pairs of bases on opposite DNA (or DNA and RNA) strands.

Concentration gradient
The gradual change in the concentration of a substance from one area to another. Diffusion occurs down a concentration gradient.

Condensation
The process by which a gas turns into a liquid.

Cone cell
Light receptor cell in the eye which is sensitive to colour.

Continuous data
Numerical data that can have any value within a range (e.g. length, volume or temperature).

Contraceptive
A method of preventing pregnancy that can be hormonal or non-hormonal.

Control experiment
An experiment that's kept under the same conditions as the rest of the investigation, but doesn't have anything done to it.

Control group
A group that matches the one being studied, but the independent variable isn't altered. It's kept under the same conditions as the group in the experiment.

Control variable
A variable in an experiment that is kept the same.

Cornea
The transparent outer layer at the front of the eye. It refracts (bends) light into the eye.

Coronary bypass surgery
Surgery that takes a healthy piece of blood vessel and uses it to bypass a blocked coronary artery (an artery supplying the heart).

Corpus luteum
A structure developed from the remainder of a ruptured follicle following the release of an egg during ovulation. It produces progesterone.

Correlation
A relationship between two variables.

Crop rotation
A method of growing different crops in the same area each year in a cycle to prevent the soil from being depleted of nutrients.

Cytokinesis
The process by which the cell membrane and cytoplasm divide to form two separate cells.

Cytoplasm
A gel-like substance in a cell where most of the chemical reactions take place.

D

Decomposer
An organism (e.g. a microorganism such as a bacterium or a fungus) that breaks down dead organisms and organic matter.

Decomposition
The breakdown of dead organisms and organic matter.

Denatured (enzymes)
The point at which an enzyme no longer functions as a catalyst due to the altered shape of its active site.

Dendron
An extension of a neurone, which carries nervous impulses towards the cell body.

Denitrifying bacterium
A bacterium that turns nitrates (nitrogen-containing ions) in the soil into nitrogen gas.

Dependent variable
The variable in an experiment that is measured.

Desalination
The removal of salts (mineral ions) from salt water.

Dialysis
A treatment for kidney failure where a machine does the work of the kidney by removing waste products from the blood.

Diffusion
The spreading out of particles from an area of higher concentration to an area of lower concentration.

Diploid
When a cell contains two copies of each chromosome (one from each parent).

Discrete data
Numerical data that can only take certain values with no in-between value (e.g. number of people).

DNA (deoxyribonucleic acid)
The molecule in cells that stores genetic information.

Dominant allele
The allele for the characteristic that's shown by an organism if two different alleles are present for that characteristic.

Double-blind trial
A clinical trial where neither the doctors nor the patients know who has received the drug and who has received the placebo until all the results have been gathered.

Drought
A lack of fresh water in an area due to a lack of precipitation (i.e. not enough rain).

E

Ecosystem
A community of living organisms with the abiotic parts of their environment.

Effector
Either a muscle or gland which responds to nervous impulses.

Egg cell
A gamete (reproductive cell) that carries the female DNA for sexual reproduction.

Endocrine gland
A gland that secretes hormones into the bloodstream.

Endothermic reaction
A reaction where energy is taken in from the environment.

Environmental gradient
A gradual change in an abiotic factor (e.g. light intensity) across a habitat.

Environmental variation
The differences between individuals of the same species caused by environmental factors.

Enzyme
A large protein that acts as a biological catalyst.

Epidemic
A big outbreak of disease.

Epidermal tissue
A type of plant tissue which covers the surface of a plant.

Erythrocyte
Another name for a red blood cell.

Ethene
A hormone produced by plants that controls cell division and stimulates ripening.

Eukaryotic cell
A complex cell containing a nucleus, such as a plant or animal cell.

Eutrophication
An excess of nutrients in water, which leads to increased algal growth, oxygen depletion and the eventual death of organisms living in the water.

Evaporation
The process by which a liquid turns into a gas.

Evolution
The changing of the inherited characteristics of a population over time.

Exchange surface
A specialised surface in an organism used for the exchange of materials, e.g. gases and dissolved substances.

Exothermic reaction
A reaction which transfers energy to the environment (usually via heat).

F

Fair test
A controlled experiment where the only thing that changes is the independent variable.

Family pedigree
A diagram which shows how a characteristic (or disorder) is inherited in a group of related people.

Fertilisation
The fusion of male and female gametes during sexual reproduction.

Fertiliser
A substance added to soil to increase the soil's nutrient content.

Flagellum
A long-hair like structure present on some bacterial cells, which rotates to make the cell move.

Follicle (ovaries)
An egg and its surrounding cells.

Follicle-stimulating hormone (FSH)
A hormone produced by the pituitary gland involved in the menstrual cycle. It causes eggs to mature in the ovaries.

Food security
Having access to enough food that is safe to eat and has the right balance of nutrition.

Fungus
A type of eukaryotic organism that includes mushrooms, yeasts and mould. Some fungi are able to cause disease.

G

Gamete
A sex cell, e.g. an egg cell or a sperm cell in animals.

Gene
A short section of DNA, which contains the instructions needed to make a specific protein (and so controls the development of a characteristic).

Gene pool
The number of different alleles in a population.

Genetically modified (GM) organism
An organism which has had its genome altered through genetic engineering.

Genetic engineering
The process of transferring a useful gene from one organism's genome to another organism's genome.

Genetic variant
A different form of a gene (produced by a mutation).

Genetic variation
The differences between individuals of the same species caused by differences in their genes.

Genome
All of the genetic material in an organism.

Genotype
What alleles you have, e.g. Tt.

Gibberellin
A type of plant hormone that stimulates seed germination, stem growth and flowering.

Glomerulus
A network of capillaries located at the start of a kidney nephron. Ultrafiltration happens here.

Glucagon
A hormone produced and secreted by the pancreas when the blood glucose level is too low. It causes glycogen to be converted back into glucose, increasing the blood glucose level.

Glycogen
A molecule that acts as a store of glucose in liver and muscle cells.

Gravitropism
The growth of a plant in response to gravity. Also known as geotropism.

Guard cell
A cell found on either side of a stoma, which controls the stoma's size.

H

Habitat
The place where an organism lives.

Haemoglobin
A red pigment found in red blood cells which carries oxygen.

Haploid
Containing half the number of chromosomes that's in a normal body cell.

Hazard
Something that has the potential to cause harm (e.g. fire, electricity, etc.).

Health
A state of complete physical, mental and social well-being and not merely the absence of disease or infirmity.

Heart rate
The number of times a heart beats per minute.

Herd immunity
The prevention of an outbreak of disease through the immunisation of a large percentage of the population.

Heterozygous
Where an organism has two alleles for a particular gene that are different.

Homeostasis
The regulation of conditions inside your body (and cells) to maintain a constant internal environment, in response to changes in both internal and external conditions.

Hominid
A member of the classification family containing humans and their ancestors.

Homozygous
Where an organism has two alleles for a particular gene that are the same.

Hormone
A chemical messenger which travels in the blood to activate target cells.

Hybridoma
A cell made by fusing a mouse lymphocyte with a tumour cell, which is used to produce lots of monoclonal antibodies.

Hypothalamus
An area of the brain which controls and monitors body temperature.

Hypothesis
A possible explanation for a scientific observation.

I

Immune system
The structures and processes that protect the body against disease.

Immunisation
The process of giving a patient immunity to a certain pathogen through the injection of a small amount of the dead or inactive pathogen.

Immunity
The ability of the white blood cells to respond quickly to a pathogen.

Inbreeding
When closely related animals or plants are bred together.

Independent variable
The variable in an experiment that is changed.

Indicator species
A living organism, the presence or absence of which can be used to assess pollution in an area.

Insulin
A hormone produced and secreted by the pancreas when the blood glucose level is too high. It causes the body's cells to take up more glucose from the blood, reducing the blood glucose level.

Interdependence
The dependence of organisms on each other in order to survive and reproduce.

Interphase
The stage in the cell cycle when the cell grows, the amount of subcellular structures increases and the DNA is copied.

Iris (eye)
The coloured part of the eye. Changes shape to control how much light enters the eye.

L

Lactic acid
The product of anaerobic respiration that builds up in muscle cells.

Lens (eye)
Transparent structure in the eye that refracts (bends) light onto the retina.

Ligase
An enzyme that joins pieces of DNA together.

Limiting factor
A factor which prevents a reaction from going any faster.

Lipase
A type of enzyme that catalyses the conversion of lipids into glycerol and fatty acids.

Lipid
A large biological molecule made up of fatty acids and glycerol.

Long-sightedness
The inability to focus on near objects.

Luteinising hormone (LH)
A hormone produced by the pituitary gland, which stimulates egg release (ovulation).

Lymphocyte
A type of white blood cell which can produce antibodies or antitoxins against microorganisms.

Lysogenic pathway
A part of the life cycle of a virus where viral genetic material is incorporated into the genome of the host cell.

Lytic pathway
A part of the life cycle of a virus that involves replicating itself using the enzymes and proteins of a host cell.

M

Magnification
How much bigger an image is than the real object that you're looking at.

Malnutrition
A condition where a person doesn't have the right balance of nutrients to stay healthy.

Mean (average)
A measure of average found by adding up all the data and dividing by the number of values there are.

Median (average)
The middle value in a set of data when the values are in order of size.

Medulla oblongata
An area at the top of the spinal cord and base of the brain, that controls unconscious activities e.g. breathing and heart rate.

Meiosis
A type of cell division where a cell divides twice to produce four genetically different haploid gametes. It occurs in the reproductive organs.

Memory lymphocyte
A type of white blood cell that remains in the body for a long time and has the ability to 'remember' and recognise a specific antigen.

Menstrual cycle
The monthly sequence of events in which the female body releases an egg and prepares the uterus (womb) in case it receives a fertilised egg.

Menstruation
The bleeding that occurs during the first stage of the menstrual cycle as the uterus lining is shed.

Meristem tissue
Tissue found at the growing tips of plant shoots and roots, which is made up of cells that are able to differentiate.

Mitochondria
Structures in a cell which are the site of most of the reactions for aerobic respiration.

Mitosis
A type of cell division where a cell reproduces itself by splitting to form two genetically identical offspring.

Mode (average)
The most common value in a set of data.

Model
A representation of an object or system that is used to describe or display how that object or system behaves in reality.

Monoclonal antibody
Antibodies produced from lots of clones of a single white blood cell, which will only target one specific antigen.

Monohybrid cross
The study of the inheritance of one gene.

Motor neurone
A nerve cell that carries electrical impulses from the CNS to effectors.

mRNA (messenger RNA)
The molecule that carries the code from DNA in the nucleus to the ribosomes in the cytoplasm, so that a protein can be made.

Multiple alleles
There being more than two alleles for a single gene.

Mutualism
A relationship between two organisms, from which both organisms benefit.

Myelin sheath
A fatty layer surrounding the axon of some neurones, which acts as an electrical insulator and speeds up nervous impulses.

N

Natural selection
The process by which species evolve.

Negative feedback
A mechanism that restores a level back to normal in a system.

Nephron
A structure in the kidney where filtration of blood takes place.

Neurone
A nerve cell. Neurones transmit information around the body, including to and from the CNS.

Neurotransmitter
A chemical that transmits a nerve impulse across a synapse.

Nitrate
A nitrogen-containing ion with the formula NO_3^-.

Nitrifying bacterium
A bacterium that turns ammonia from decomposing matter into nitrites or nitrites into nitrates (nitrogen-containing ions).

Nitrogen-fixing bacterium
A bacterium that turns nitrogen gas in the air into nitrogen-containing ammonia.

Non-communicable disease
A disease that cannot spread between individuals.

Non-indigenous species
A species that does not naturally occur in an area.

Nucleotide
A repeating unit in DNA and RNA that consists of a sugar, a phosphate group and a base.

Nucleus (of a cell)
A structure found in eukaryotic cells (e.g. animal and plant cells) which contains genetic material that controls the activities of the cell.

O

Obesity
A condition were a person is very overweight and has too much body fat.

Oestrogen
A hormone produced by the ovaries which is involved in the menstrual cycle.

Oral transmission
A route of transmission of a disease where food or water contaminated with a pathogen is swallowed.

Osmoregulation
The control of the water level in the body.

Osmosis
The movement of water molecules across a partially permeable membrane from a region of higher water concentration to a region of lower water concentration.

Ovary
An organ in the female body which stores and releases eggs. It is also a gland and secretes the hormone oestrogen.

Ovulation
The release of an egg from an ovary.

P

Palisade mesophyll tissue
Leaf tissue where most photosynthesis happens.

Pancreas
An organ (and gland) in the mammalian digestive system. It produces insulin and glucagon to control blood sugar level.

Parasitism
A relationship between two organisms, where one organism (the parasite) takes what it needs to survive but the other organism (the host) doesn't benefit.

Partially permeable membrane
A membrane with tiny holes in it, which lets some molecules through it but not others.

Pathogen
An organism that causes disease, e.g. a bacterium, virus, protist or fungus.

Pentadactyl limb
A limb with five digits, e.g. a human hand, a bat's wing.

Phagocyte
A type of white blood cell which engulfs foreign cells.

Phagocytosis
The process by which white blood cells engulf and digest foreign cells.

Phenotype
The characteristics you have, e.g. blue eyes.

Phloem
A type of plant tissue which transports dissolved sugars around the plant.

Photosynthesis
The process by which plants use light energy to convert carbon dioxide and water into glucose and oxygen.

Phototropism
The growth of a plant in response to light.

Pituitary gland
A gland located in the brain that is responsible for secreting various hormones.

Placebo (in drug testing)
A substance that looks like the drug being tested but doesn't do anything.

Plasma
The liquid component of blood, which transports the contents of the blood around the body.

Plasmid
A small loop of DNA, present in some bacterial cells, which is not part of the main chromosome.

Platelet
A small fragment of a cell, which helps blood to clot at a wound.

Population
All the organisms of one species living in a habitat.

Potable water
Water that is suitable for drinking.

Precipitation
Any water that falls to the Earth from clouds, e.g. rain, snow or hail.

Preclinical trial
A set of drug tests on human cells, human tissues and live animals that occurs before clinical trials.

Predation
Where an organism (the predator) hunts and kills another organism (the prey) for food.

Prediction
A statement based on a hypothesis that can be tested.

Primary consumer
An organism in a food chain that feeds on a producer.

Producer
An organism at the start of a food chain that makes its own food using energy from the Sun.

Progesterone
A hormone produced by the ovaries, which is involved in the menstrual cycle.

Prokaryotic cell
A small, simple cell, without a nucleus, e.g. a bacterium.

Protease
A type of enzyme that catalyses the conversion of proteins into amino acids.

Protein
A large biological molecule made up of long chains of amino acids.

Protist
A eukaryotic, single-celled organism. Some protists are able to cause disease.

Pulmonary artery
A blood vessel which transports deoxygenated blood from the heart to the lungs.

Pulmonary vein
A blood vessel which transports oxygenated blood from the lungs to the heart.

Pupil (eye)
The hole in the front of the eye, through which light enters.

Q

Quadrat
A square frame enclosing a known area which can be used to study the distribution of organisms.

R

Random error
A difference in the results of an experiment caused by things like human error in measuring.

Range
The difference between the smallest and largest values in a set of data.

Reaction time
The time it takes to respond to a stimulus.

Recessive allele
An allele whose characteristic only appears in an organism if there are two copies present.

Red blood cell
A cell, which forms part of the blood, that transports oxygen around the body.

Reflex
A fast, automatic response to a stimulus.

Reflex arc
The passage of information in a reflex.

Reforestation
The replanting or regrowth of forests in areas where they have been removed.

Relay neurone
A nerve cell in the CNS that carries electrical impulses from sensory neurones to motor neurones.

Repeatable result
A result that will come out the same if the experiment is repeated by the same person using the same method and equipment.

Reproducible result
A result that will come out the same if someone different does the experiment, or a slightly different method or piece of equipment is used.

Reproductive cycle
The time it takes for an organism to produce independent offspring.

Resolution (instruments)
The smallest change a measuring instrument can detect.

Resolution (microscopes)
The ability to distinguish between two parts. A higher resolution gives a sharper image.

Respiration
An exothermic reaction which releases energy for metabolic processes and occurs continuously in every cell of living organisms.

Restriction enzyme
An enzyme that recognises specific DNA sequences and cuts the DNA at that point.

Retina
Layer at the back of the eye that contains light receptor cells.

Ribosome
A structure in a cell, where proteins are made.

Risk
The chance that a hazard will cause harm.

Risk factor
Something that is linked to an increased likelihood that a person will develop a certain disease.

RNA polymerase
The enzyme involved in producing mRNA from a DNA template.

Rod cell
Light receptor cell in the eye which is sensitive to light intensity.

S

Sampling
Taking a number of organisms from a population to study.

Secondary consumer
An organism in a food chain that eats a primary consumer.

Selection pressure
Something in an organism's environment that affects its chance of surviving and reproducing, e.g. competition, predation, disease.

Selective breeding
When humans artificially select the plants or animals that are going to breed so that the genes for particular characteristics remain in the population.

Selective reabsorption
The absorption of useful substances (including glucose, some ions and the right amount of water) back into the blood from the kidney nephrons.

Sensory neurone
A nerve cell that carries electrical impulses from sensory receptors to the CNS.

Sensory receptor
A group of cells which are sensitive to a stimulus and initiate a response to that stimulus. E.g. light receptor cells in the eye are sensitive to light.

Sex chromosome (humans)
One of the 23rd pair of chromosomes, X and Y — together they determine whether an individual is male or female.

Sex-linked genetic disorder
A disorder caused by an allele present on a sex chromosome.

Sexually transmitted infection (STI)
An infection caused by a pathogen that is transmitted through sexual contact.

Sexual reproduction
Where two gametes combine at fertilisation to produce a genetically different new individual.

Short-sightedness
The inability to focus on distant objects.

SI unit
A unit of measurement recognised as standard by scientists worldwide.

Specialised cell
A cell which performs a specific function.

Sperm cell
A gamete (reproductive cell) that carries the male DNA for sexual reproduction.

Statins
A group of drugs that can reduce the amount of 'bad' cholesterol in the bloodstream to help slow the rate of fatty deposits forming in blood vessels.

Stem cell
An undifferentiated cell which has the ability to become one of many different types of cell or more stem cells.

Stent
A wire mesh tube that's inserted inside an artery to help keep it open.

Sticky end
A section of unpaired bases at the end of a DNA molecule, which allows two pieces of DNA to be joined together.

Stimulus
A change in the environment.

Stoma
A tiny hole in the surface of a leaf.

Stomach ulcer
A hole in the lining of the stomach.

Stratigraphy
The study of rock layers.

Stroke volume
The volume of blood pumped by one ventricle each time it contracts.

Subcellular structure
A part of a cell, e.g. the nucleus, a chloroplast.

Synapse
The connection between two neurones.

Systematic error
An error that is consistently made every time throughout an experiment.

T

Target organ
A particular organ on which a hormone acts.

Tertiary consumer
An organism in a food chain that eats a secondary consumer.

Testis
A gland in the male body which secretes the hormone testosterone.

Testosterone
The main male reproductive hormone, produced by the testes.

Theory
A hypothesis which has been accepted by the scientific community because there is good evidence to back it up.

Thermoregulation
The control of body temperature.

Thermoregulatory centre
An area of the brain, located in the hypothalamus, which controls and monitors body temperature.

Thyroid gland
A gland which produces the hormone thyroxine.

Thyroxine
A hormone secreted by the thyroid gland that controls metabolic rate.

Tissue culture
When cells are grown on or in an artificial growth medium.

Transcription
The first stage of protein synthesis, in which an mRNA copy of a gene is made using a strand of DNA as a template.

Transect
A line which can be used to study the distribution of organisms along an environmental gradient.

Translation
The second stage of protein synthesis, in which amino acids are joined together by ribosomes to make a polypeptide (protein).

Translocation
The movement of food substances (i.e. dissolved sugars) around a plant.

Transpiration stream
The movement of water from a plant's roots, up through the xylem and out of the leaves.

Trial run
A quick version of an experiment that can be used to work out the range of variables and the interval between the variables that will be used in the proper experiment.

tRNA (transfer RNA)
The molecule that carries amino acids to ribosomes in the cytoplasm, so that proteins can be made.

Trophic level
A stage in a food chain.

Tumour
A growth of abnormal cells.

Type 1 diabetes
A condition where the pancreas produces little or no insulin, which means blood glucose can rise to a dangerous level.

Type 2 diabetes
A condition where the pancreas doesn't produce enough insulin, or when a person becomes resistant to their own insulin, which means blood glucose can rise to a dangerous level.

U

Ultrafiltration
The filtration of substances through a membrane at high pressure, e.g. from the glomerulus to the Bowman's capsule in the kidney nephrons.

Uncertainty
The amount of error your results might have.

Urea
A waste product produced from the breakdown of amino acids in the liver.

Uterus
The main female reproductive organ and where the embryo develops during pregnancy. (Another word for the womb.)

V

Vacuole (plant cells)
A structure in plant cells that contains cell sap and maintains the internal pressure of the cell.

Valid result
A result that is repeatable, reproducible and answers the original question.

Valve (in the circulatory system)
A structure within the heart or a vein which prevents blood from flowing in the wrong direction.

Variable
A factor in an investigation that can change or be changed (e.g. temperature or concentration).

Variation
The differences that exist between individuals within a species.

Vasoconstriction
When blood vessels supplying the skin capillaries constrict (get narrower).

Vasodilation
When blood vessels supplying the skin capillaries dilate (get wider).

Vector (in disease)
An organism that carries and transmits a pathogen from one host to another, but does not suffer from the disease that the pathogen causes.

Vector (in genetic engineering)
Something used to transfer DNA into a cell, e.g. a virus or a bacterial plasmid.

Vein
A blood vessel that carries blood to the heart.

Vena cava
A blood vessel (vein) which transports blood into the heart from the rest of the body (excluding the lungs).

Ventricle
A chamber of the heart which pumps blood out of the heart through either the pulmonary artery or the aorta.

Virus
A disease-causing agent which lives and replicates within host cells.

W

White blood cell
A cell which forms part of the blood and part of the immune system, helping to defend the body against disease.

X

Xylem
A type of plant tissue which transports water and mineral ions around the plant.

Z

Zero error
A type of systematic error caused by using a piece of equipment that isn't zeroed properly.

Zygote
The diploid cell formed when two gametes fuse at fertilisation.

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Data used to construct the measles graph on page 185 From: Immunisations, Vaccine and Biologicals. Measles Global Annual Reported Cases 1980-2014. Measles Graph: http://www.who.int/immunization/monitoring_surveillance/burden/vpd/surveillance_type/active/measles/en/

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